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DEPARTMENT OF TRADE AND INDUSTRY

Report of the working party on traffic and capacity at Heathrow

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This report was completed by the working party in July 1970. It is now being published in the Civil Aviation Publications series in the hope that it may be of some interest to others in the civil aviation world.

1 Introduction

1.1 Task of the Working Party

1.1.1 *Alleviation of congestion at Heathrow*

1.1.1.1 An airport is that part of an air transport system in which passengers and freight consignments are transferred between the air and ground stages of their journeys. The maximum rate at which this can be done, i.e. the capacity of the system, will be determined by: (a) the rate at which aircraft can land and take off: (b) the availability of aircraft stands and terminal facilities to process the embarkation and disembarkation of passengers and freight: and (c) the capacity of the surface transport access system. The Working Party has been concerned with the first of these factors and with the second in so far as stand availability might affect aircraft movements.

1.1.1.2 The capacity of Heathrow is, in practice, limited to the amount of traffic which can be handled safely and expeditiously in the air and on the ground. There are certain minimum separation distances (or times) which must, for reasons of safety, be maintained between successive movements and from these it is possible to calculate the maximum number of movements which can safely be allowed to take place in any given period of time; it is on this basis that long-term estimates of Air Traffic Control (ATC) capacity are made. In the short-term the Controllerate of National Air Traffic Control Services (NATCS) in conjunction with the airlines operating into the airport sets limits each year on the hourly rates at which landing and take-off movements can be scheduled; the present practice is for these limits to be expressed as a 'sustained' rate (i.e. one which can be operated for long periods) and a (higher) 'maximum' rate which can be operated for only one or two hours of the day. These annual limits are set on an empirical basis by reference to the performance during the previous year, the expected demand for the coming year and any known local factors which will be relevant in that period. Year by year, as ATC techniques have developed, these limits have been increased. In order to keep the scheduled movements within these limits a scheduling control system exists to consider the requirements of each airline and allocate the 'slots' in an appropriate manner. It is already the case that demand at certain times exceeds the limits so that some operators are obliged to re-schedule some of their movements.

1.1.1.3 With the rapid growth in aircraft movements which is taking place at Heathrow each year and is likely to continue, substantial re-scheduling of planned services will become increasingly necessary if unacceptable delays are to be avoided. But such re-scheduling of flights can carry with it economic penalties for the operators in the same way as do the delays resulting from congestion and there are therefore limits on the amount of re-scheduling which operators will accept. In addition, since the number of

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jet flights which may be operated in the period from 2330 to 0600 BST is restricted in the interest of reducing disturbance from noise, re-scheduling is only possible during day-time; with the growth in traffic now forecast, the periods during which the movements scheduled reach the ATC maxima will rapidly increase.

1.1.1.4 Congestion can be reduced by re-scheduling flights so that demand is not allowed to go above the maximum permissible level; this will result in the 'peak' of demand being broader. Congestion can also be reduced by the transfer of some services to other airports—Gatwick for example. Accordingly, in February 1968, the Working Party was set up to ascertain the probable air traffic demands and capacity which would be available at Heathrow; to consider to what extent congestion could be reduced by transfers to Gatwick, and to ascertain the ability of Gatwick to accommodate such traffic as might be transferred.

1.1.2 *Commission on the Third London Airport* (*The Roskill Commission*)
1.1.2.1 On the same day as the meeting that led to the formation of the Working Party, the President of the Board of Trade announced in Parliament that the Government had decided to re-open the question of the siting of the third London airport, and proposed to set up an independent commission for this purpose. In May, when the Working Party's studies were already in progress, the Government announced the setting up of the new commission under the Chairmanship of the Honourable Mr Justice Roskill with the following terms of reference:

> To enquire into the timing of the need for a four-runway airport to cater for the growth of traffic at existing airports serving the London area, to consider the various alternative sites, and to recommend which site should be selected.

1.1.2.2 It was clear that the work being undertaken by the Working Party could be of use to the Commission and, in addition, that if some extension of the original scope of its work were agreed, material could be provided which would assist the Commission in their consideration of the timing of the need for the third London Airport. It was accordingly decided that the scope of the Working Party's investigations should be so extended.

1.2 Terms of reference

We were given no formal terms of reference; but the events described in the previous paragraphs have led us to adopt the following interpretation of our task:

> (i) To consider to what extent congestion at Heathrow can be alleviated by the transfer of services from there to Gatwick and the timing of the need for such transfers; and
> (ii) to provide material for the Roskill Commission on air traffic forecasts and capacity for London relevant to the Commission's consideration of the timing of the need for a third London airport.

1.3 Membership and meetings

Our initial membership comprised representatives of the following:
- Board of Trade, including representatives of the National Air Traffic Control Services;
- British Overseas Airways Corporation;

British European Airways;
British Airports Authority.

Later we were joined by representatives of

British Eagle International Airlines (until its demise at the end of 1968);
British United Airways (after the demise of British Eagle).

In addition representatives of the Secretariat of the Commission on the Third London Airport began to attend as observers in October 1968 and have been present at most of the subsequent meetings. Our first meeting was held on 28 March 1968, and we have met twenty seven times in all.

1.4 Approach adopted by the Working Party

1.4.1 Since the problem was obviously concerned with the peaks of demand the Working Party decided to adopt the following approach to its task:

1.4.1.1 to forecast a range of annual totals of passenger demand and of demand for air transport movements at the main airports in the London area up to 1985;

1.4.1.2 to estimate, from the annual forecasts, the hourly pattern of aircraft movements at Heathrow during selected days in each year up to 1975 (figures were later produced also for 1976 and 1978 to enable consideration to be given to those years); the method of arriving at these hourly distributions is explained in Appendix 3 to this Report;

1.4.1.3 to use a fast-time computer simulation model of the air traffic control system serving Heathrow as it was assumed to be in the mid 1970s;

1.4.1.4 to feed the hourly traffic patterns at 1.4.1.2 and the NATCS forward estimates of assumed time distributions between successive movements into the model in order to assess for given years what delays were likely to arise from the various rates and patterns of traffic presenting themselves at different periods during that year;

1.4.1.5 to use the information resulting from 1.4.1.4 to estimate the shape of delay distributions at Heathrow;

1.4.1.6 to estimate the future capacity of the other main airports in the London area;

1.4.1.7 to estimate the extent to which the delays could be reduced by re-scheduling flights out of the peaks and by transferring flights to Gatwick.

1.4.2 The Working Party set up a subgroup to carry out the detailed forecasting under 1.4.1.1 and 1.4.1.2; this subgroup consisted of representatives from the Statistics Division (Stats), Economic Services Division (ESD), The Directorate of Operational Research and Analysis (DORA) (all of the Board of Trade), and the British Airports Authority (BAA); the airline representatives preferred to make their points in the full Working Party meetings. The Working Party considered and accepted the subgroup's findings (now set out at Appendix 1 to this Report—see also Paragraph 2.4 and Appendix 5).

1.4.3 The work of determining the ATC rules and procedures to be used in the simulation (mentioned at 1.4.1.3 above) was carried out by a Working Party on Heathrow and Gatwick Capacities, set up in April 1968, under the chairmanship of the Director of Control (Plans) (DC(P)) of NATCS; a copy of the report of that Working Party is at Appendix 2 to this Report.

1.5 Information presented to the Roskill Commission

1.5.1 The report of the subgroup referred to in subparagraph 1.4.2 above prepared by the subgroup during 1968, was presented to the Roskill Commission in April 1969 and has now been published by the Commission as part of their Papers and Proceedings Vol. VIII, Part 2.

1.5.2 Paragraph 2.4 below explains how and why the above forecasts were re-examined early in 1970 in the light of the actual traffic figures for 1969; and what the results of that re-examination were. Those forecasts which were revised and an explanation of the factors taken into account are contained in Appendix 5 to this Report. The information contained in Appendix 5 was presented to the Roskill Commission in April 1970.

2 Forecast of air traffic for the London area for each year up to 1985

2.1 Method of forecasting

2.1.1 The method used to develop the air transport forecasts and the assumptions on which they are based are described in sections 3 to 6 of Appendix 1 to this Report. The non-air-transport movements were considered separately and it was agreed that whilst some, e.g. the airlines' non-revenue flights, were a necessary adjunct to the air-transport operations, the other non-air-transport movements could and should be dissuaded from using the peak hours. Thus, although non-revenue flights would increase in number with the general rise in movements, the total number of non-air-transport movements per hour should remain steady. It was therefore decided that non-air-transport movements according to the daily numbers and diurnal shape of the movements observed during July 1969 should be included in the simulation model: during the busy hours from 0800 to 1700 hours the number included varied between 4 and 6 movements per hour.

2.1.2 The air transport traffic at the London area airports was first analysed by its constituent markets (N. America, other long-haul, European, Irish, domestic) each divided into scheduled and non-scheduled services. These were expected to grow at different rates and with differing characteristics. The balance between these various elements is expected to change over time and the resulting forecast was in effect a combination of forecasts within the constraint of an estimated total air traffic demand. Note was also taken of the changing use of the different airports by different types of services (e.g. the increasing use of Luton, Stansted and Gatwick for charter flights) insofar as this may affect the level and distribution of future traffic.

2.2 Aggregate London area (Heathrow and Gatwick) forecasts

The forecasts of the long-term trend in the growth of traffic currently using Heathrow and Gatwick Airports are given in tables 1 and 2 of Appendix 1; table 1 gives the passenger forecast and table 2 that of air transport movements.

2.3 Heathrow and Gatwick forecasts to 1975

2.3.1 The above London area forecasts were broken down into figures of demand for Heathrow and Gatwick separately. Traffic at London in 1967 and 1968 was below the levels indicated by long-term trends due, it was assumed, to economic factors such as the immediate effects of sterling devaluation and the limitations on overseas travel spending by UK residents. However, since these factors were held to be fairly short-lived, the Heathrow and Gatwick forecasts include assessments of the way in which the passenger and aircraft movements might move towards the forecast trends. Here again the method of calculation and the breakdown of the figures by markets are given in Appendix 1 (section 7 and tables 5–8); forecasts of annual totals of passengers and aircraft movements for the two airports up to 1975 are given in tables 5 and 6 (Heathrow) and 7 and 8 (Gatwick).

2.4 Revision of forecasts

2.4.1 Air traffic forecasts are normally reviewed at about yearly intervals and such a review of the above forecasts was made early in 1970. Some changes have been made and the revised forecast together with the reasons for these revisions are in Appendix 5. Re-assessment of trends in passenger traffic have led to small upward adjustments in the North American market and lower growth rates for domestic traffic, resulting in a slightly lower total passenger forecast up to 1975 and a slightly higher forecast thereafter. Whereas in the previous forecast the same rates of increase in passengers per plane had been assumed with the lower, most likely and upper passenger forecasts, a re-examination of the relationships between passenger growth and increases in passengers per plane has led to marginally lower rates of increase in planeloads for the most likely and lower passenger forecasts. This has reduced the range of the estimates for aircraft movements, leaving the upper limit about the same but increasing the most likely and lower limit growth in aircraft movements. The revised passenger and aircraft forecasts for the London area are in tables 1 and 2 of Appendix 5.

2.4.2 Separate estimates for Heathrow and Gatwick (shown in tables 5 to 8 in Appendix 1 to this Report) were arrived at by dividing the total forecast demand for the London area on the basis of those categories of demand that have, in the past, been served at Heathrow and Gatwick. The demise of British Eagle at the end of 1968 caused a reduction in the volume of services operated at Heathrow and this has been matched by increases in traffic at Gatwick in 1969 on domestic scheduled and international charter services. There may be further transfers of traffic between the two airports but no account has been taken of those beyond a small diversion, from 1970 onwards, of European traffic from Heathrow to Gatwick, stemming from the establishment of BEA Air Tours at Gatwick. Compared with the forecasts in Appendix 1 these revised estimates (shown in tables 3 to 6 of Appendix 5) put back Heathrow's aircraft movement growth by up to one year before 1975 but the difference is negligible in 1980. The effect at Gatwick is to advance the aircraft movement forecasts by three years.

2.4.3 The British Airports Authority considers that the revised forecasts take insufficient account of the likely growth in movements by all-cargo aircraft. This has most impact on table 4 ('Forecasts of Air Transport Movements at Heathrow') of Appendix 5. In the BAA's view, the forecast for the total air transport movements labelled 'most likely' should be regarded as a lower estimate and the forecast labelled 'upper' should be regarded as the most likely estimate.

(Note: At present all-cargo movements take second place to the mixed passenger/cargo movements in the busy hours. If, as seems likely, the scheduling control system (see para. 1.1.1.2 above) continues to operate in this way, the numbers of all-cargo movements will have little effect upon traffic in the busiest hours.)

2.5 Comparison with earlier forecasts

The last comprehensive London area traffic forecasts published by the Government were those in Appendix 1 of the 1967 White Paper on the Third London Airport (Cmnd 3259). These forecasts were presented, for each year shown, as an 'upper level' (which would almost certainly not be exceeded) and a 'lower level' (which almost certainly would); a 'most likely' level was also indicated for both the passenger and movement forecasts. Comparison of these 1967 figures with the present forecasts shows that, in the case of numbers of movements, the 'upper level' figures almost coincide but that the present 'lower level' and 'most likely' level are rather higher than their 1967 counterparts.

3 Assessment of the ability of Heathrow to meet the forecast demand

3.1 Effective limitation on Heathrow's capacity

3.1.1 The various factors affecting the movement of passengers and freight through Heathrow airport are referred to in paragraph 1.1.1 where it is stated that the Working Party decided to concern itself with:

(a) the rate at which aircraft can take off and land at the airport;
(b) the availability of aircraft stands and terminal facilities.

3.1.2 As regards the limitation stated at (b) above the Working Party obtained information from the BAA on the expected capacity of aircraft stands and passenger terminals at Heathrow in the early 1970s. This information related to existing facilities and to existing committed plans for expansion. The BAA assured the Working Party that, possibly with some minor modification and development, existing facilities and existing commitments for expansion would cope with the expected growth of traffic at Heathrow up to a sustained movement rate of at least 72 movements per hour with the mixture of aircraft types expected by the mid 1970s. Further development of facilities would be required to cater for higher volumes of sustained movement and for changes in aircraft mix after the mid 1970s. BAA's programme of expansion is continually evolving in consultation with the major airlines and therefore the Working Party agreed that it would be reasonable to assume that ground facilities would not become a limiting factor at least up to 1978.

3.2 Measurement of ATC capacity

3.2.1 The provision of runway capacity for an aircraft requiring to land or take-off is basically similar to services provided in other fields of customer demand such as the requirement for connections at a telephone switchboard or for consultations in a doctor's surgery. If a new customer arrives before the previous customer has been served the new arrival has to wait; the more quickly demand can be met, the more customers can be served. The number of landings, take-offs or mix of landings and take-offs that can be accommodated on runways is limited by the separations ATC imposes between successive movements on or in the vicinity of the runways in the interests of safety of the traffic concerned. These separations are not uniform. A three mile separation is aimed for between aircraft on final approach at Heathrow; a number of different time and distance intervals is used to separate successive departures depending upon their routeings and the take-off/climb performance of the aircraft; and different rules again are applied to effect the necessary safe separation between movements on the runways themselves. Intervals between successive movements are further affected by variations in the times taken by aircraft in passage through the different parts of the system. These variations are partly attributable to difference in aircraft performance, partly to changes in operating conditions and partly to variation in performance of the pilot and air traffic control officer. Thus the achievable capacity of a runway and ATC system is not a fixed or precise measure but a statistical quantity arising from the variation in the 'servicing' times for the arrival and departure control of the traffic. The mean or average value of, say, the number of movements per hour achievable (the mean runway acceptance rate, that is, the 'Service Rate'—see para. 3.1 of Appendix 4 to this Report) may be used to indicate approximately the working capacity of the runways. And it must be noted that the working capacity of the system (i.e. ATC working in 'top gear') can be realised only when there is continual traffic demand requiring attention.

3.2.2 If the time interval taken by the ATC to sequence each aircraft were constant—i.e. in a constant 'service' rate—and the aircraft arrived for service in a steady stream separated by that interval, then they would all be served without delay and at full utilisation. However, whenever the demand rate of the traffic exceeds the servicing capability queueing or congestion develops and delays ensue for some aircraft. There is considerable diurnal fluctuation in the traffic demand within the Terminal Area (TMA) and this is particularly the case during the peak hours of summer days when the mean demand of traffic is maintained at or increases beyond the mean service rate of the control system: in these circumstances queues will grow and delays will increase. Therefore estimates of the capability or capacity of the ATC system to provide a service to the varying intensities of summer demand traffic have to take into account not only the number that can be served but also the amount and variation of the delays that must be incurred by the aircraft.

3.2.3 *Theory of queues*

A branch of applied mathematics, queueing theory, has been developed to tackle problems of congestion in systems. It provides estimates of the probabilities of queue length and the associated delays for given levels of utilisation. Much of its success depends upon the simplification which can validly be made in the development of a mathematical model of the main factors and processes of the system being studied. However the modelling of a large complex system such as ATC can soon become intractable mathematically and it may become necessary to use the method of simulation to provide estimates of delay.

3.2.4 *Traditional method of assessing capacity*

Demand for runway capacity does not conform to simple rules and the service intervals are subject to considerable variation depending on the nature of the aircraft movements involved. Nevertheless, in the absence of any other method, and faced with the need to produce rough estimates of the long term runway capacity of an airport, simple queueing theory has been used; this theory indicates that if the level of utilisation of the facility is at about 80 per cent of the service rate then all other things being equal the customers will be subjected to only a small average delay (approximately 4 minutes) and the situation would be containable. Thus for airports a service rate was derived from an estimated average service interval and a rate of utilisation at 80 per cent of the service rate was assumed to be one which could be sustained indefinitely with only small average delays.

3.2.5 *Discovering the inter-action of demand and delay through simulation*
As the need emerged to produce more accurate estimates of capacity and to determine what would happen to the level of delays as demand approached closer to—or passed—the service rate it was felt that an alternative method was needed. The Working Party was informed that DORA had been studying the inter-action of demand and delay at Heathrow and, noting the extent to which performance of the ATC system was dependent upon the instantaneous nature of the demand, and the exact sequence of events which preceded it, had concluded that a simulation model of the system would be the best tool for the job. This simulation would have the advantage that a number of operational modes could be contained within the one model and the effect of a variety of different ATC procedures could be assessed directly and in considerable detail. Consequently a fast time simulation model was already being prepared by DORA and the DC(P) Working Party of the NATCS (see para. 1.4.3) decided to adopt this approach. The output of the simulation model was to be in the form of detailed forecasts of the probability of various levels of delay associated with the forecast of demand; and an estimate of the degree to which the position could perhaps be improved by constraining demand rather than allowing it to rise as forecast.

3.3 Simulation of Heathrow operations in mid 1970s

3.3.1 In order to test the ability of Heathrow to meet the traffic demand forecast by the subgroup referred to in para. 1.4.2 it was necessary for the model to simulate ATC performance at that airport in the mid 1970s. Estimates were produced in the form of distributions of times expected to be taken by traffic in parts of the ATC system simulated for inclusion in the model (the origins of these estimates and their values are stated and explained in Appendix 2 to this Report). These values showed an improvement over present performance expected to accrue from improved techniques and the tighter disciplines imposed by increased pressure of demand. The DC(P) Working Party decided that no credit should be taken at this stage for further improvements that might accrue from the inclusion of a computer in the intermediate approach part of the ATC system as this element is still in the early stages of development study.

3.3.2 Having noted from the output of the model that the 1974 'most likely' level of demand upon the system did not appear to produce significant problems it was decided to focus attention on the post 1974 part of the decade.

3.4 Analysis of output of the fast time simulation

The simulation model output showed that:

(a) when the two main runways at Heathrow are used in the segregated mode (i.e. one being used exclusively for landings and the other for take-offs) the service rate indicated for the airport is 38 arrivals and 46 departures per hour;
(b) so long as the demand upon the airport does not exceed 90 per cent of this rate a stable queueing situation occurs with a mean delay of about 5 minutes;

(c) as an example, table 1 below shows the position with regard to the 1978 'most likely' forecast of arrivals in the segregated mode and compares the delays arising from the forecast demand with the results of restricting the maximum demand to 90 per cent of the service rate and accommodating the excess demand in the less busy hours.

Table 1

Comparison of delays arising from forecast demand with those at 90 per cent of the service rate: 1978 segregated mode arrivals

Forecast demand		Demand restricted to 90 per cent of service rate	
Mean delay	90 per cent probability delay	Mean delay	90 per cent probability delay
17 mins	27 mins	5 mins	11 mins
(see figure 6 of Appendix 4)		(see figure 8 of Appendix 4)	

(Note: The delays shown are those experienced during the forenoon peak—0900 to 1200 hours—on the typical summer day.)

3.5 Discussion of results

Following our receipt and study of the report on the results of the simulation the airlines' representatives were asked to give the considered views of their companies on what was likely to be an acceptable level of delay and what degree of traffic management (by 're-scheduling'—see para. 4.2.2 below) would be possible. In broad terms their advice was that, basing their judgement on the details supplied and the figures produced by the simulation (now forming part of Appendix 4 to this Report), a mean delay figure of 5 minutes was acceptable; and that the existing traffic management procedures would deal with the situation up to about 1976. However, it seemed likely that the degree of traffic management necessary to restrict the mean delay to about 5 minutes would, after 1976, probably be considerable. Airlines might therefore be placed in the position of having to choose between operating at a time somewhat removed from the time they originally selected, moving some of their flights to another London airport or not operating all their intended flights to London. Possible methods of dealing with the situation after 1976 are discussed below.

4 Possibilities of alleviating congestion at Heathrow

4.1 Method of approach

4.1.1 The Working Party considered that, given the limited possibilities of expanding the ATC capacity and the high and increasing level of demand for services which airlines wish to operate at peak periods at Heathrow, there will be, after 1976, increasing difficulty in meeting these demands. We have assumed that NATCS will in fact continue their present practice of indicating, after consultation with the airlines, the maximum numbers of landings and take-offs at Heathrow that can be accommodated with small delays; and that the airlines will abide by these limits. The increasing demands will make it ever more necessary to manage the traffic (so as to encourage the transfer of flights to other airports and to ensure that additional flights are added to the schedules only in such a way as to keep within the prescribed maxima). While this pressure will encourage the use of larger aircraft at peak hours—and we believe that the larger aircraft will increasingly be used—we do not consider that, in the light of our forecasts of passenger demand and aircraft movements, the use of such aircraft will, by itself, provide an answer to this problem. Nor do we expect that the airlines using Heathrow—particularly the foreign airlines—will be willing to accept indefinitely the 're-scheduling' of some of their flights to off peak hours. Rather than operate at such times they may cancel or re-route flights they might otherwise operate to London. Pending the construction of a third London airport—which would provide a long term solution—there appear to be three main methods of dealing with the expected traffic demands at Heathrow:

(a) to continue, by traffic management, to spread the peak traffic on the lines explained above (with the consequence that some of the airlines might prefer to serve other airports in the London area at which they could operate at the desired time; or reduce their proposed operations to London);

(b) impose a distribution of traffic at and between London's airport by governmental action (this again might mean some loss of traffic);

(c) institute a differential pricing policy in order to match the demand for airport capacity to what is available (again with the possibility of some loss of traffic).

4.1.2 The Working Party considered that until the costs and benefits of each method were established there could be no way of knowing which means would be most efficient. The Economic Services Division of the Board of Trade advised the Working Party that there were two ways of discovering the costs and benefits; either a long and complex research project into the costs must be undertaken; or a system of differential pricing must be introduced which would cause the airlines to count the cost for themselves and act accordingly.

4.2 Transfers to Gatwick and other sources of alleviation

4.2.1 The first part of the Working Party's terms of reference is concerned with establishing the degree to which the congestion at Heathrow can be alleviated by transferring to Gatwick some of the services which would otherwise use Heathrow; this problem is considered at para. 4.2.3 below. It is, however, necessary to look also at certain other possible sources of alleviation and these are also examined below.

4.2.2 '*Re-scheduling*' *out of peaks*

4.2.2.1 Since the limits on capacity at Heathrow now envisaged for the mid 1970s and beyond are higher than the present limits, the 'transfers' and 're-scheduling' will be largely a question of ensuring that growth stays within these limits. Nevertheless, in attempting to assess the impact on the airlines of the concept of restricting demand to 90 per cent of the service rate, it is convenient to think in terms of the forecast unconstrained demand (that is demand as it is assumed it would be if the degree of traffic management currently exercised by the scheduling control system were to be maintained but *not* increased) for a given year being cut back to that level. To this end—and to assess the number of movements (on the basis of our traffic forecasts) which would be likely to exceed the 90 per cent of service rate level in the years 1974, 1976 and 1978—a line can be drawn across each of the graphs for those years (Figs. 9A to 14B of Appendix 4) at the desired level (i.e. 34 arrivals/42 departures) and the numbers of movements above that line read off. (These graphs show the forecasts for the 15th busiest day of each year; however, with the continuing spread of peak traffic between days as well as hours, the 15th busiest day could by the mid 1970s be almost matched by the 30th or 40th busiest day.) The results of such an exercise are shown in table 2 below.

Table 2

Movements per day in excess of the levels of 90 per cent of service rate: 'most likely' level of forecasts

	Movements per day above 90 per cent service rate	
Year	Arrivals	Departures
1974	9	Nil
1976	17	4
1978	30	8

(Note: These figures apply to the segregated mode as now simulated and are for the peak summer period.)

4.2.2.2 If the lines across the graphs at 90 per cent of service rate are taken as a ceiling then it can be seen (Figs. 9A to 14B of Appendix 4 to this Report) that in 1974—and to a lesser extent in 1976—there are troughs below that line adjacent to the peaks and capable of accepting the excess flights. However, by 1978 the peaks are higher and broader-based while the troughs are correspondingly shallower, thus necessitating a degree of 're-scheduling' which could well be unacceptable to the airlines. It is, of course, the case that the airline operators will be interested as much in the length of time by which re-scheduled movements would be displaced as in the numbers alone; an examination of this position was carried out and the results are set out in table 3 below.

Table 3

Degree of daily re-scheduling; numbers of aircraft and length of time involved

Year.		Arrivals	Departures
1974	Number of aircraft	9	—
	Aircraft hours	9	—
	Maximum shift (hours)	1	—
1976	Number of aircraft	17	4
	Aircraft hours	20	4
	Maximum shift (hours)	2	1
1978	Number of aircraft	30	8
	Aircraft hours	46	16
	Maximum shift (hours)	4	3

(Notes: 1. 'Aircraft hours' is the result of adding together the individual products of each aircraft to be shifted and the length of that aircraft's shift.
2. 'Maximum shift' is the length of time of the longest shift necessary for any one aircraft.)

4.2.2.3 Both tables 2 and 3 above utilise the figures from the forecasts in Appendix 1 to this Report—that is, based on the division of traffic between Heathrow and Gatwick arrived at in 1968. As a result of the re-examination of this division, it seems that the growth of Heathrow traffic will be a little slower. This will obviously reduce the figures in tables 2 and 3 but only marginally and the later the period the less will be the effect; by 1978 it can safely be ignored. (See the final paragraph of Appendix 5 to this Report)

4.2.2.4 The tables in this section (particularly tables 2 and 3) are derived from the graphs attached to Appendix 4 to this Report; they are intended as indications of the nature and scale of the problems under discussion and are not, and should not be treated as, precise estimates.

4.2.3 *Transfers to Gatwick*

4.2.3.1 In considering the possibility of transferring flights to Gatwick as a means of easing Heathrow congestion we have had to bear in mind the existing use already being made of Gatwick, the fact that that usage is increasing more quickly than had been expected (see Appendix 5), and the unresolved question whether a second runway should be built at Gatwick. A computer simulation of Gatwick's future traffic was not carried out but the evidence we received from the Directorate of Control (Plans) was that the single runway sustainable maximum capacity of Gatwick should be taken as between 35 and 40 movements per hour (depending on the mix of traffic, etc.) and rising slightly under pressure to the mid 1970s. If a second runway were to be built at Gatwick it would obviously increase that airport's capacity; but it is not clear at present how big the increase would be. It seems possible that a second runway would, because of terrain difficulties, have to be in such a position that the distance between the centrelines of the two runways would be insufficient to permit them to be operated independently. This could necessitate phasing the landings on one runway to take account of take-offs on the other (in order to guard against overshoots) and this would reduce utilisable runway capacity so that it could never be as high as the capacity of the two main runways at Heathrow, which can be operated independently. If it were necessary to phase the landings and take-offs at Gatwick the sustainable capacity would be between 45 and 50 movements an hour; should it prove possible to achieve a measure of independence in the operations, the sustainable capacity might be capable of expansion to something over 60 movements an hour.

4.2.3.2 The degree of relief which Gatwick can provide for Heathrow will, of course, decrease with time as Gatwick's own traffic builds up. (See Appendix 6 to this Report which deals with Gatwick's ability to accept transfers.) On balance it seems safe to conclude that even with a single runway Gatwick can provide some relief to Heathrow in the mid 1970s. For example, in 1976 and on the 'most likely' level forecast, Gatwick could, at busy hours, accept between 5 and 10 movements per hour without itself running into severe delays; by 1978 (again on the 'most likely' forecast) the level of Gatwick's own traffic could have built up to such a level that a one-runway airport would have little or no relief to offer. A second runway would make it possible to transfer some 10 to 20 movements an hour (depending on the additional capacity provided by such a runway—see para. 4.2.3.1 above) from Heathrow to Gatwick in 1978; however, at that point in time, those movements would represent only 2 to 3 years growth (again depending on capacity assumed) in peak hour movements for the London area.

4.2.4 *Transfers to other south-east airports*

The Working Party has not considered what relief, if any, might be provided by airports outside the London area. Some thought has, however, been given to the position of Stansted, Luton and Southend airports. No simulation runs were undertaken in respect of these airports but from a statistical analysis the position with regard to any relief they might be able to provide during the critical period appears to be as follows:

(a) *Stansted.* In 1969 there were some 42,500 aircraft movements at Stansted; of these 5,300 were air transport and two-thirds of these were non-scheduled. Thus the large majority of aircraft movements at Stansted at present are non-air-transport (i.e. testing, training and general aviation flights) but the transfer by Channel Airways of their operations from Southend to Stansted in 1968 resulted in a considerable increase in air transport movements compared with earlier levels. The current capacity of Stansted is limited by the capacity of the terminal facilities; moreover, the Government has stated that the forecast traffic would not exceed 50,000 total movements a year up to 1972. Although within these two constraints air transport traffic could probably double from its 1969 level of about 220,000 terminal passengers and 5,300 air transport movements, Stansted could obviously in the short term make no significant contribution to the relief of Heathrow. Once a decision is made on the site for the Third London Airport, Stansted's role in the medium term future would be clearer and obviously additional capacity could be provided. We are advised by the BAA that terminal facilities could probably be expanded within the present airport boundary to match a throughput of up to 3 million passengers. However, because of the uncertainty whether such development would take place and because the airlines now using Heathrow would probably prefer to transfer to Gatwick rather than to Stansted, we consider that there is very limited scope for Stansted to contribute directly to the relief of congestion at Heathrow.

(b) *Luton.* The current high figures for aircraft movements indicate that Luton is already taking some overspill from Heathrow; some of the services previously operated by British Eagle at Heathrow have in fact been taken up by operators at Luton since British Eagle's demise. There has been a particularly big increase in charter activity at Luton and this is expected to continue. The potential at Luton for accepting overspill from Heathrow is dependent upon a number of factors:

(i) the extension of facilities at the airport to permit the maximum use of the runway: this is presently the subject of a public inquiry;
(ii) the possible future restrictions on the use of the airport, if one of the inland sites is chosen for the third London airport, which would discourage operators from transferring services to Luton;
(iii) any ATC restraint imposed by gliding activity from Dunstable;
(iv) any restrictions which might be imposed as the result of noise problems in the area;
(v) the impracticability of operators being able to transfer to Luton all or coherent parts of their London area operations to relieve pressure on Heathrow at peak periods.

To sum up, Luton as an unconstrained single runway airport could theoretically provide some further capacity for Heathrow overspill until the late 1970s but it seems probable that the natural growth of traffic at the airport and the various limiting factors are likely to prevent any significant relief during this period.

(c) *Southend.* The limitations on operations at Southend arising from both runway length and noise-abatement measures make it impossible for the airport to play any significant role in relieving the pressure of air transport at Heathrow.

4.2.5 *Other sources of alleviation*

There are also some other possible sources of alleviation for Heathrow. An increasing use of the existing smaller airfields in the London area by general aviation flights could ease the situation by removing some of those flights from the major airports. A short take-off/landing runway could perhaps be laid down at Heathrow and/or Gatwick and could help to free some extra slots on the main runways; alternatively, an entirely new STOL airport (or airports) might be built. But unless and until substantial use is made of STOL aircraft of ample seating capacity (which does not at present appear to be likely before the end of the present decade, if then) any relief so gained would probably be marginal.

5 Summary

5.1 The airport capacity available both at Heathrow and Gatwick is already subject to certain limitations. There is at Heathrow a Board of Trade limit on the number of jet movements which may be operated at night and a similar restriction will be imposed at Gatwick in 1971 in place of the present voluntary limitation by airlines. In addition, a maximum is set by the Air Traffic Control Service in conjunction with the airlines on the number of landings, and of take-offs, which may be scheduled, day or night, in any one hour. These maxima are announced annually and, because of improvements in air traffic control techniques, it has been possible to raise them considerably over the past years. If the total number of landings or take-offs proposed by the airlines in any one hour exceeds the respective maximum, the airlines' schedules are adjusted, the excess movements being re-scheduled into adjacent hours where 'slots' are still available, so that average delays greater than the presently accepted level can be avoided.

5.2 On occasion some re-scheduling by the airlines has been necessary. It could therefore be argued that Heathrow Airport has already reached 'saturation point'. Alternatively, it could be claimed that Heathrow cannot be said to be saturated until every hour throughout the year is occupied to the limit. Both of these extreme views have been discarded by the Working Party as being unrealistic. The Working Party has noted that no generally acceptable definition of airport saturation has been arrived at, so far, by the various international bodies which are concerned with civil aviation.

5.3 The method followed by the Working Party as described in this Report has been to develop a computer simulation model which we have used to test the expected traffic demands in the busiest periods against the maximum capacity which the Air Traffic Control Service expect to be able to provide in future years, taking into account all factors which seemed to us relevant, including ratio of arrivals to departures, the mixture of aircraft types, the airlanes used and the mode of runway utilisation; we have also allowed for some 'peak spreading' (i.e. re-scheduling out of the busiest hours) based on the present level of such re-scheduling with appropriate annual increases. This has indicated when delays—and what magnitude of delays—can be expected in the period we have studied. Using the concept of the service rate (as described in paragraph 3 of the paper at Appendix 4), we have been able to estimate the number of movements which will have to be transferred from the peak hours at Heathrow. We have also estimated to what extent, in the years concerned, capacity will be available at Gatwick to accommodate movements which might be transferred to that airport from Heathrow. Before setting out our conclusions, however, we should like to place on record the assumptions which we have used, since if these assumptions prove to be incorrect the estimates will, of course, prove to be incorrect also.

5.4 The assumptions we have made are as follows:

(a) The rates of traffic flow in the period we have considered will lie within the range of our forecasts and close to the level indicated as 'most likely'. (This is, to an extent, a misnomer since the forecasting was done on the basis of a range for each year between the 'upper' level and the 'lower' level; and for statistical purposes no one level within that range is any more likely than another. But for ease of reference a level has been indicated, roughly in the middle of the range, and called the 'most likely'.)

(b) The National Air Traffic Control Service will continue to indicate annually the maxima for the movements to be scheduled at the airports and the airline operators will continue to arrange their schedules and operate their flights so as jointly to keep within the indicated limits.

(c) Apart from disruptions arising, for instance, from adverse weather conditions, actual operations during the period under consideration will be within about plus or minus 10 per cent of those scheduled (this is the performance achieved at present).

(d) The expected improvements in ATC techniques as forecast in Appendix 2, will in fact take place and these maxima will thus continue to rise at least until 1974.
(Note: While some increase in airport capacity can be expected if Computer Assisted Approach Sequencing (CAAS) is introduced at Heathrow during the period, it is still too early in the development study of this idea for it to be taken into account in our forecasts: no plans have yet been made for CAAS to be introduced at Gatwick.)

(e) Other possible constraints (e.g. aprons, terminal buildings, access roads) will not prove to be limiting factors at Heathrow and Gatwick during the period we have studied i.e. up to 1978.

(f) No revolutionary changes will come about in aircraft performance in commercial airline operations or in ATC techniques during the period we have studied.

(g) The use of STOL or VTOL aircraft during this period will be small and will not have a substantial effect on our forecasts.

(h) The availability of airspace outside the airport terminal zone will not place a constraint on traffic.

6 Conclusions

On the basis of these assumptions we have reached the following conclusions:

(a) If the scheduled demand is allowed to rise above (or even up to) the mean service rate (or runway acceptance rate) congestion grows and there is an increasing trend in the average delays to the traffic. However, if the scheduled demand is re-arranged so as not to exceed about 90 per cent of the mean service rate in any hour, the resulting average delay to traffic is roughly constant at about 5–6 minutes throughout the peak hours. (See Fig. 8 of Appendix 1 to this Report.)

(b) On the basis of the information produced by simulation it is the considered view of the airlines that a level of sustained mean delay during the peak hours of about 5–6 minutes is acceptable. The airlines also consider that the extra re-scheduling of flights (over and above that already taking place now) necessary during the period up to and including the year 1974 to limit the scheduled demand to 90 per cent of the service rate would be acceptable. (Calculations of the amount of such re-scheduling depend upon the accuracy or otherwise of the assumptions set out above but we estimate that such services as have to be re-scheduled could be accommodated within one hour of the time originally planned.) By 1976 it will become impossible for all the movements which would have to be re-scheduled to be accommodated within one hour of the preferred time and some would perhaps have to shift by 2 hours. However, we believe that the transfer at peak periods of some 20 movements a day (and about half of these would be from the single busiest hour) would, if spread over the busiest hours, permit the demand in the peak summer months at Heathrow to be contained to within 90 per cent of the service rate.

(c) Between 1976 and 1978 an increasing number of movements will have to be transferred from Heathrow during the peak hours if traffic is to be kept within the 90 per cent of the service rate limit. Precise estimates are not possible but the computer studies indicate that in 1978 the number of movements which should be re-scheduled from the peak hours (not all of them, however, for transfer to another airport) might, in the peak summer months, be in the region of 40 per day (possibly some 16 from the single busiest hour). Figure 8 of Appendix 4 to this Report shows the results of re-scheduling the forecast demand of segregated arrivals for the peak period of 1978 so as to keep within the limit of 90 per cent of service rate; it will be seen that (if no transfers to Gatwick take place) the 'peak hours' would run from 0600 to 1200 and from 1500 to 1900; and that throughout those 10 hours the

demand would be at the maximum permissible level.
(Note: In order to put the position into perspective it is probably necessary to point out that by 1978 the unconstrained demand during the hours 0600 to 1200 and 1500 to 1900 would, for arrivals, be 376 and that the number to be moved would therefore be about 9 per cent of the total. It is probably also fair to comment, when thinking of mean average ATC delays of 5–6 minutes, that there are also delays for non-ATC reasons (e.g. aircraft unserviceability) which can be substantial.)

(d) Despite the difficulty of providing accurate estimates of the capacity which will be available at Gatwick (see para. 4.2.3.1 above) we consider that—certainly up to 1976—Gatwick should be able to accommodate up to 10 movements an hour transferred from the peak hours at Heathrow. Traffic peaks at the 2 airports do not at present coincide (largely, we believe, because of the different composition of the traffic at each) and if this non-coincidence should continue there would be more usable capacity at Gatwick at the times most helpful as a relief to Heathrow. After an increase if a second runway is built the amount of spare capacity at Gatwick will, of course, diminish as its own traffic increases, but even with one runway there should continue to be some spare capacity at Gatwick up to 1978.

(Note: All the foregoing estimates of dates and capacities are based on the assumption in para. 5.4(a) above that traffic demand will lie close to the level indicated as 'most likely'. The effect upon the indicated dates if traffic demand, in the event, reaches the lower or upper limits, rather than the most likely, can be summarised by saying that up to 1975, for air transport movements, the 'upper' level is about a year ahead of the 'most likely', while the 'lower' level is about 2 years behind: after 1975 (because of the widening of the range of forecasts) these gaps increase to 2 years and 4 years respectively. For the 'numbers of passengers' forecasts, the one year ahead/2 years behind relationship persists until 1980.)

(e) Because the assumptions set out in paragraph 5.4 may, to a greater or lesser degree, be falsified by events, we consider that it would be most imprudent to assume that the conclusions set out above indicate that, for some years to come, no action need be taken to relieve the pressure on Heathrow. It is clearly possible that the amount of re-scheduling referred to above may need to be greater, and may prove more difficult to achieve, if the assumptions we have used prove in the event to be incorrect. Although we feel reasonably confident regarding the conclusion reached in (b) above, and believe that in these early years the present system should ensure that demands at peak periods will be accommodated without the need for drastic alteration in the schedules proposed by the airlines, we cannot, even here, regard this situation as wholly satisfactory. The growing pressure for space at Heathrow and the increasing difficulties with which airlines will be faced in obtaining space at the most popular hours may have the effect of depriving London of certain air services which could otherwise have been operated. It is not within the scope of our Working Party to attempt to assess the costs and benefits of this loss of traffic, but in the absence of any indications to the contrary we do not consider that its loss would be beneficial. Accordingly, we would not regard our conclusions as justifying inaction in this matter and we therefore make the recommendations set out in the following paragraph.

7 Recommendations

7.1 The conclusions in para. 6 above provide the best answers the Working Party can give to the questions posed by the first part of its terms of reference (the second part was concerned simply with providing information for the Roskill Commission).

7.2 We consider, however, that in the light of the conclusion at 6(e) above, we ought to go beyond the letter of our terms of reference and recommend that further action should be taken, bearing in mind particularly paragraphs 4.1.1 and 4.1.2 of this Report.

7.3 First, we recommend that the improvements in ATC techniques and performance, both by the NATCS and by airlines (on which the increased capacity at Heathrow which we have forecast largely depends) should be regularly reviewed so that the ATC capacity can be reassessed; and that in addition the earliest practicable opportunity should be taken to assess the effects of introducing the Computer Assisted Approach Sequencing system (CAAS).

7.4 Secondly, we recommend that there should be further studies of the capacity and delay probabilities at Heathrow and the other London area airports by use of the simulation model; and that these studies should include the use of the 'tactical mixed mode' (that is, allocating take-offs and landings to either runway in a manner that will make maximum possible use of the time available on both). Although this method of runway working is in fact now used at Heathrow to some extent, we have not been able fully to consider all its implications in our studies.

7.5 Thirdly, we recommend that a study should be undertaken of the contribution which changes in the system of airport charges, including differentials on a basis other than that which applies at present, could make to the solution of the problem of congestion at Heathrow.

7.6 Fourthly, we recommend that a study should be undertaken of the longer term role to be played by Gatwick in the London area airports pattern, this study to include the advantages of the provision of a second runway.

7.7 We believe that if these recommendations are put into effect they should provide—together with the annual review of forecasts (mentioned in para. 2.4.1 above)—an increasingly accurate picture of both demand and capacity at the London area airports. Meanwhile, we assume that the existing practice of declaring annually the maximum numbers of landings and take-offs which can be scheduled at Heathrow will continue; and that the scheduling control system will ensure that the operations by airlines remain within the indicated limits.

APPENDIX 1

London air traffic forecasts

A slightly abridged version of the report appearing in the Papers and Proceedings of the Commission on the Third London Airport vol VIII part 2, section 1, pages 25–43 and retains the original paragraph numbering.

Introduction

4.1 The Working Party on Traffic and Capacity at London's Airports, convened by the Board of Trade, including representatives of the BAA and the British airlines, and latterly assisted by members of the Secretariat of the Commission on the Third London Airport understands that the Commission is in urgent need of advice on forecasts of:

4.1.1 total passenger demand and demand for aircraft movements by market in the London area for each year up to 1985 on a long term trend basis,

4.1.2 the same traffic up to 1975 taking account of short term factors; and

4.1.3 the hourly distribution of aircraft using Heathrow on selected busy days for each year up to 1975.

The rest of the paper accordingly presents and explains the Working Party's agreed forecasts on these topics.

Definition of London area

4.2 For the present purpose we have confined our London area forecast to forecasts of the growth of the traffic at present using Heathrow and Gatwick. Naturally, the development of traffic at all the airports in the home counties that serve public transport operations is relevant to the timing of the need for a third London airport.

4.3 Trend forecast of total annual air passenger demand in the London area up to 1980

4.3.1 *Forecasting methods used*

4.3.1.1 The forecasting work carried out by the Working Party was of two broad, but distinct, kinds. There were first projections made by fitting algebraic formulae to statistics of the past and using these formulae to predict the future; and secondly there were projections formed by modifying or continuing past trends in accordance with judgments on how these trends can be expected to be moulded by the economic and other forces that bear on them.

4.3.1.2 Both these methods have their advantages and disadvantages. The use of formulae based on data from the past may enable future air traffic to be derived from forecasts of other economic quantities which are more easily predicted than air traffic itself; and it ensures that tendencies that have been present will continue to be reflected in the forecast, even though the causes are unknown. It is, however, possible that some part of a formula, relatively unimportant over the period to which the formula is fitted but serving to improve the approximation to the facts that the formula represents, may take on a more dominant role in the forecast period. The other method, which rests more on economic argument, is probably less precise, relies more on the quality of the forecasters' judgment, and renders more difficult a quantitative assessment of the confidence that can be placed in the range of the forecast.

4.3.1.3 The choice of method in such cases will probably rest heavily not only on whether it yields a forecast which has credibility and inspires confidence, but also on whether it affords explanations, in terms of the factors known to be operating, of the form it takes. The Working Party decided not on this occasion to base its forecast on an algebraic formula. The formulae that had been calculated for the London area did not make use of many of the economic and other variables widely thought to be important. These, and other similar formulae that could have been derived, were capable of giving different results during the forecast period whilst fitting past data equally well. Nevertheless the Working Party decided that it should not ignore the formulae that had been derived and that, if they produced forecasts markedly different from those produced by other methods, good explanations for the differences should be found before they were rejected.

4.3.2 *Confidence in the forecast and its range*

4.3.2.1 Forecasting is not exact: inexactitudes arise from the variability of the factors with which we are dealing, from uncertainties and errors in the statistics used and in estimates derived from them, and from possible misjudgements. Accordingly, the Working Party has produced, not a single projection, but a range of possibilities. The range widens the further ahead we look. The range selected is one in which there can be reasonable confidence that the outcome will be covered by the span of the forecast, though it is impossible to measure this degree of confidence precisely.

4.3.2.2 BEA have entered the reservation that their forecasts (based on the total short haul market and not on their own movements alone) are lower than the Working Party's—particularly in respect of 'domestic' and 'Irish' traffic. In the case of the forecast in total numbers of passengers BEA's figures are below the Working Party's lower limit; however, since BEA also envisage a slower rate of growth in the average number of passengers per aircraft than does the Working Party, their forecast of the numbers of movements to be expected falls between the Working Party's 'most likely' and 'lower limit' figures. The Working Party, while adhering to the forecast range expressed in this paper and its attached tables, has noted BEA's views.

4.3.3 *The passenger forecast: international*

4.3.3.1 The London area airports are primarily engaged in international transport and figure very largely as terminals for international passenger movement. About four-fifths of the passenger traffic at London's airports is international and this traffic is more than three-quarters of the international air traffic at all United Kingdom airports. More than 60 per cent of passengers entering and leaving the United Kingdom travel by air; this proportion has been growing and is likely to continue to grow. London area air passenger traffic is, therefore, closely linked with total international passenger movement.

4.3.3.2 Leaving aside traffic across the land border with the Irish Republic, which is mainly local, the UK international travel market is made up of sea and air travel. In many ways these two transport modes cater for different kinds of demand for travel, yet the numbers of passengers carried by each have changed in ways similar to those that would have been expected of a single market composed of two parts—sea transport and air transport—with substitution at the margin.

4.3.3.3 The rate of growth of passenger traffic by sea and air together into and out of the United Kingdom has been remarkably stable at about 9 per cent a year over the last 15–20 years. We reviewed the forces at work, or expected to come into play in the next decade, that might operate to accelerate or retard the expansion of international passenger travel. On the side of buoyancy, the largest international markets—those to and from Europe and to and from North America—have been growing faster than total travel between the UK and the rest of the world. The increasing importance of the faster growing markets could raise the rate of increase of total international travel, although to the extent that these markets are gaining at the expense of slower growing markets the scope for these above average rates of growth will lessen. Continued growth of international travel at rates of similar order to those of the past implies an increasing share of disposable income spent on international travel by those groups of people from which travellers into and out of the United Kingdom are mainly drawn. However, consumers' expenditure on travel and associated items is a sufficiently small proportion of domestic income for this to impose no restraint on traffic growth at past, or somewhat higher than past, rates even though there will be other growing demands on consumers' discretionary income.

4.3.3.4 The Working Party decided that there were no strong reasons for forecasting the most likely growth of international passenger travel at a rate other than the 9 per cent of the past; any reasons that there were for taking a different view were covered by the inevitable uncertainties of forecasting—uncertainties arising from the errors of estimating underlying growth rates in the past and from the imprecision of any calculation of current trend values. In setting limits within which we have a high degree of confidence the traffic will lie we took account of the consequences for international travel of the recent slower growth stemming partly from policies at home (including devaluation) designed to achieve a permanent shift in the allocation of resources from consumption to exports and investment. Some of these policies, such as devaluation, may have the effect of increasing the number of overseas visitors to the United Kingdom; but these are fewer than the number of United Kingdom residents who travel abroad, and the boost to foreign traffic is not likely to outweigh the adverse effect on overseas travel by U.K. residents.

4.3.3.5 Methods and reasoning similar to those employed above in the context of total international travel have been used with some modifications to project international travel in each of the main markets and to estimate sea travel within the total. The modifications recognise that for the longer journeys there is less substitution between sea and air travel. This is what we would expect on general grounds and is in accordance with the evidence from the past.

4.3.3.6 International air passenger forecasts can now be made. Over the period 1968–1980 traffic growth is forecast at rates commencing at about 12 per cent a year and declining to about 11 per cent a year by the end of the period. These rates also apply to the large European market. Traffic to and from Ireland is likely to grow less quickly, at rates falling from about 8½ per cent a year to about 6½ per cent a year, whilst in the North American market they might run from 15 per cent a year down to about 11 per cent a year. Other long-haul traffic is forecast to expand at about 13 per cent a year. These forecasts continue the slow decline in the rate of growth of all passenger traffic carried by air that has been observed in the past. Within the total the forecast for the North American routes is, on the information available to us, consistent with the forecast of North Atlantic traffic now being made for ICAO. Most of the international air traffic to and from the United Kingdom will pass through London area airports. The proportion of total international air traffic that uses these airports will continue to rise as a consequence of the changing market pattern of the traffic, since the fast growing long-haul services are more concentrated at the major international airports than are short-haul services.

4.3.4 *Passenger forecast: domestic*

Domestic air traffic is more difficult to forecast. It is, however, a relatively small part of air traffic at London. The United Kingdom is limited in size and there is a network of railways and roads linking the main centres of population and industry. With easy and fairly rapid surface transport the proportion of total domestic traffic carried by air is very small. Considerations of what might happen to the total market are of little value in forecasting air traffic. For this same reason no sudden incursion of air transport into the markets of surface operators can be foreseen. There have been periods of rapid growth in domestic air travel in the past. These seem to have been associated with large fare reductions or special cheap tickets; domestic air fares have risen sharply in recent years and there may be further increases to come. Domestic air transport is little used by holiday-makers so that the buoyancy expected in international travel will be absent. Though domestic traffic may grow less quickly than international traffic there is evidence of substantial interlining between domestic and international services. Various estimates of the scale of this interlining at London have been made from the results of surveys made for other purposes. The estimates centre on a figure of about one-third of domestic journeys being for the purpose of making an air connection. This suggests that the growth of international traffic may prevent the growth rate of domestic traffic from sinking far. We decided to predict growth of domestic traffic at an average rate of 8½ per cent per year, with outer limits of 7 per cent and 10 per cent per year, until 1980, with a slowing down of the rate of expansion similar to that forecast for international traffic.

4.3.5 *Total passenger forecasts*

4.3.5.1 The line of reasoning we have so far followed assumes implicitly that the effects of a number of extraneous factors on air traffic at London are negligible or will continue to operate in future much as they have done in the past. However, some of these factors merit special consideration.

4.3.5.1.1 *Channel tunnel.* The biggest impact of the tunnel, if built, in diverting passenger traffic from other means of transport will be felt on the short routes between the south coast and nearby European countries. The tunnel is likely to be most attractive to travellers taking their cars with them and most of these move by sea at present. Much of the air traffic diverted to the tunnel will be from routes at airports in south-east England outside the London area. The tunnel is likely to cause some reduction in air traffic at London on routes to near European capitals such as Paris, Amsterdam and Brussels, but the amount diverted is not expected to be large. Estimates used in planning the tunnel are small in relation to the forecast of European air traffic at London's airports.

4.3.5.1.2 *Hovercraft.* Much the same considerations apply as to the Channel tunnel. These vehicles are, primarily, an alternative to other forms of surface travel.

4.3.5.1.3 *Other technological developments in surface transport.* Faster and more frequent train services and a more extensive motorway network could well attract some passenger traffic from the domestic air routes. This is one of the factors taken into account in setting the growth rates for domestic air traffic.

4.3.5.1.4 *V/STOL.* It is not thought that these aircraft, apart from some small STOL aircraft, could be in service much before 1980, if by then. Since these vehicles are aircraft the traffic they might carry is properly included in the forecast, and transfers of traffic to them from other kinds of aircraft do not alter the total volume of air traffic. If V/STOL services can operate cheaply they might generate new air traffic. This is not likely to be substantial by 1985. If a V/STOL airport were constructed in the London area specially for these aircraft, a deduction in respect of the traffic using it would have to be made to the "Heathrow/Gatwick" forecasts in the tables.

4.3.5.1.5 *International services at provincial airports.* New services have been introduced from time to time and this process will no doubt continue. The scope for faster development of provincial services is limited by the need for sufficient volume of traffic to permit mounting a viable service. While a large part of our international air traffic is generated in or attracted to south-east England, profitable new routes at other places will be few and difficult to find. Nearly half London's air passengers are overseas residents and most of these want to visit London.

4.3.5.2 The passenger forecasts are set out in table 1.

4.4 Trend forecast of total annual air transport movements in the London area up to 1980

4.4.1 *Aircraft loadings*

4.4.1.1 Advancing technology makes it possible to build ever larger aircraft. The growing efficiency of airframes and engines and the higher number of seats make the newer and larger aircraft cheaper to run (in terms of seat miles flown). At the same time airlines are aware that services with smaller aircraft at higher frequency often enable them to exploit the market more effectively. In the past they seem to have attached similar importance to increasing frequencies and to lowering operating costs by using larger aircraft.

4.4.1.2 An examination of the trends of average aircraft loadings of the past together with information obtained about the orders airlines have placed for new aircraft and their equipment plans suggest that average passengers per aircraft at London might rise at about 6 per cent a year. The rate of expansion will vary for different kinds of aircraft; faster for long-haul aircraft and slower for aircraft on domestic and Irish routes. As the traffic growth rate slowly declines, raising the average age of aircraft in airline fleets, the rate of growth of average aircraft loads is likely to slow down too. We estimate that this rate of expansion will sink from above 6 per cent a year in the near future to about 5½ per cent by 1980. This implies that the average number of terminal passengers per aircraft landing or taking off would double, from about 60 in 1968 to about 120 in 1980.

4.4.2 *Freighter movements*

The statistics of aircraft loadings in the past used in this study are of average terminal passengers per air transport aircraft landing or take-off, including movements of all-cargo aircraft. The examination of changes in airline fleets in the next few years as a result of aircraft orders placed, also covered all kinds of air transport aircraft. The increases of aircraft loading derived are, therefore, averages, which include some freighter movements on which there are no passengers, and the resulting aircraft movement forecast includes freighter movements.

4.4.3 *Forecast of aircraft movements*

The forecasts are derived by dividing the passenger forecasts by the estimated average aircraft loadings: they are set out in table 2.

4.5 Extension of passenger and air transport movement forecasts from 1980 to 1985

The passenger and air transport movement forecasts in tables 1 and 2 have been extended to 1985 by continuing the predicted growth of the international travel market and sea traffic for a further 5 years with further reductions in the rate of increase of domestic air traffic. This extension continues the slow decline in the rate of expansion of air traffic at Heathrow. The margin of uncertainty described by the upper and lower alternatives continues to widen. Though the arithmetical derivation of this extension is similar to that of the forecast to 1980 the Working Party has not given the same amount of thought and consideration to it and it should be regarded as an extrapolation rather than a forecast.

4.6 Short term forecasts of total annual air traffic demand in the London area

4.6.1 The Working Party has taken the view that air traffic in the London Area in 1968 was not on trend. In that year passenger traffic was less and aircraft movements were more than they would have been if traffic were following the trends that have been predicted. The factors leading to the kind of results obtained in 1968 are of two kinds. First, passenger traffic has been depressed. The causes of this depression are to be found in the general economic conditions obtaining, particularly in the United Kingdom, in recent years. The substantial deficit in the United Kingdom balance of payments since 1964 forced the Government both to adopt economic policies that restrained the growth of incomes and expenditure and to take measures to reduce expenditure in foreign currencies. These collectively reduced the demand for air travel. The Working Party takes the view that this depression of air travel is a temporary phenomenon and that there will be a return towards trend levels in the coming years. Secondly, coincident but not directly associated with the depression in the demand for passenger travel, airlines are currently operating aircraft of a size not appreciably larger than they have been employing for some years whilst awaiting delivery of newer and substantially larger types. This has meant that for a period in the past and for a short while to come aircraft sizes, which have been growing steadily and are expected to continue to grow, are, for a spell, smaller than might have been expected. Both these departures from trend—in passenger growth and in aircraft size—will disappear in due course, but they will for a time cause passenger and aircraft movements to move differently from the forecasts that have been made. Because the prime need for these forecasts is to determine whether Heathrow is capable of accepting all the traffic offering in the next few years it is necessary to take account of these departures from trend.

4.6.2 Although growth of passenger traffic in the London area is low at the moment we expect a fairly sharp recovery some time in the next year or two. It is difficult to be precise about the timing of this, but it would probably be reasonable to expect passenger traffic to be on trend again by 1971. Thereafter passenger traffic might tend for a year or two to go above trend, but we have not felt confident enough of the timing or extent of this tendency to take account of it in our forecasts.

4.6.3 Although the average size of aircraft used in air transport continues to grow, this growth is spasmodic because of the spasmodic nature both of the development of new and larger types and of airline investment in such types. The airlines are now preparing for major re-equipment. On the longer inter-continental routes they are expecting to introduce the Boeing 747 towards the end of 1969 and this type will be appearing on the long routes in ever increasing numbers during 1970 and 1971. On the shorter routes the Boeing 727 and the Boeing 737 are entering the fleets of European operators. Before long DC9s in quantity will be in operation. BEA expect to take delivery of the Trident 3B in 1971. Because of the timing of this airline re-equipment the aircraft loadings are at present increasing less quickly than the trend rates that have been forecast. Before long these loadings will be increasing rapidly and the trend values may be regained during the period 1973–1976.

4.6.4 Using the information available about airline orders for new aircraft, adjustments have been made to the trend forecasts in tables 1 and 2. Tables 3 and 4 set out the short term forecasts of demand at airports (Heathrow and Gatwick) in the London area.

4.7 Traffic at Heathrow and Gatwick separately

4.7.1 Traffic has been growing more quickly at Gatwick than at Heathrow. There are two main reasons for different growth rates at these two airports. First, the market compositions of the traffics are different and the various markets are growing at different rates. Second, the division between scheduled and charter traffic is different and again growth rates for these two kinds of service are different. Another important reason for the faster rate of traffic growth at Gatwick may well be the greater spare capacity there than at Heathrow; we did not, however, take this factor into account in our forecasts.

4.7.2 The most important market at Gatwick is European international, although there are also domestic and long-haul (other than North American) scheduled services. The domestic and long-haul traffic at Heathrow and at Gatwick are each expected to increase at the same rate as traffic in those markets in the London area as a whole. North Atlantic and Irish traffic in the London area are predominantly at Heathrow and the London area forecasts for these markets apply to Heathrow.

4.7.3 This leaves the European international traffic to be dealt with specially. At each airport it is expected that scheduled traffic will continue to expand at rates a little lower than those for European air traffic in the London area as a whole. The remainder will be charter traffic which will continue to grow faster than scheduled traffic. In 1967, 8 per cent of international European passengers at Heathrow were carried on charter flights and, at Gatwick, 83 per cent. By 1975 these proportions might have risen to 10 and 87 per cent, respectively.

4.7.4 The forecasts for Heathrow and Gatwick are set out in tables 5–8.

4.8 Daily aircraft movements at Heathrow

4.8.1 The purpose of forecasting traffic at Heathrow on particular days and the distribution of that traffic during those days is to discover whether, and if so when, Heathrow is likely to be unable to cater for the traffic offering until 1975. This is a real practical problem and it is appropriate to consider the traffic demand that is expected rather than the traffic trends that are predicted for this period as a segment of the longer term sweep of air traffic growth. The estimates put forward are, consequently, derived from the short term forecasts described in the preceding section.

4.8.2 The Working Party has chosen for analysis and projection the traffic of three different days in 1967, one in the peak, one in the shoulder and one in the off-peak period of the year. The days chosen were the 15th and about the 150th and 250th busiest days of the year; they occurred in

August, April and January respectively. The forecasts presented here are for the corresponding days in each year until 1975. In the past some peak-spreading has occurred; traffic in the typical busy day in the peak period has been growing less quickly than the traffic for the year as a whole, in the off-peak period more quickly and in the shoulder at about the same rate. The forecast, in table 9, foresees a continuation of this trend until 1975 at least.

4.8.3 With these forecasts of daily traffic at Heathrow are associated upper and lower alternatives. For simplicity these have been derived from the upper and lower alternatives of the general forecast, though the confidence that can be placed in the out-turn lying within these limits is considerably less than the confidence associated with the limits of the annual forecast.

4.9 Hourly distributions of traffic at Heathrow on particular days

4.9.1 The timing of particular flights is determined by a number of factors some of which follow from the pattern of passenger demand for travel whilst others are constrained by airline scheduling requirements; e.g., the need to dispose aircraft over the network with high utilisation whilst avoiding night arrivals and departures, reducing the economic effects of noise restrictions and congestion, etc. The time patterns for particular categories of traffic, however, probably change only slowly over the years. The distributions for 1975, set out in table 10, are derived from the distributions within each market on the three typical days in 1967 on which the daily distributions in table 9 are based. The market distributions are those for average August, April and January days in 1975. This has been necessary because the three typical days of 1967, chosen by the Working Party for further study, have proved unrepresentative in some respects; in particular there was too little domestic traffic on the 15th busiest day of the year.

4.9.2 These forecasts are of air transport movements. Other kinds of movement, and these are numerous, can generally be kept out of the busy hours and can be ignored. There are, however, some movements, mainly positioning and an occasional test flight, that are necessary in association with air transport operations. These are few and fairly randomly distributed. According to the Heathrow records there can, frequently, be as many as three or four such movements in an hour and occasionally more. These, when they occur, will be additional to those movements forecast in the table.

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Table 1

Long term forecasts of terminal passenger demand at airports in the London area (currently Heathrow and Gatwick)
MILLIONS

	Europe			**Irish Republic**			**North America**			**Other Long-Haul**			**Total International**			**Domestic**			**Total**		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (A)	7·8	7·8	7·8	0·8	0·8	0·8	1·7	1·7	1·7	1·0	1·0	1·0	11·3	11·3	11·3	3·1	3·1	3·1	14·4	14·4	14·4
1968	8·6	8·7	8·9	0·8	0·8	0·8	1·9	2·0	2·0	1·1	1·1	1·1	12·4	12·6	12·8	3·4	3·4	3·5	15·8	16·0	16·3
1969	9·4	9·7	10·1	0·9	0·9	0·9	2·2	2·3	2·3	1·2	1·2	1·3	13·6	14·1	14·6	3·6	3·7	3·9	17·3	17·9	18·4
1970	10·3	10·8	11·4	0·9	1·0	1·0	2·4	2·6	2·7	1·3	1·4	1·5	15·0	15·8	16·5	3·9	4·1	4·3	18·9	19·9	20·8
1971	11·3	12·0	12·8	1·0	1·1	1·1	2·7	2·9	3·1	1·5	1·6	1·7	16·4	17·6	18·7	4·2	4·5	4·7	20·6	22·1	23·4
1972	12·3	13·4	14·4	1·0	1·1	1·2	3·1	3·3	3·6	1·6	1·8	1·9	18·0	19·6	21·1	4·5	4·9	5·2	22·6	24·5	26·3
1973	13·5	14·9	16·1	1·1	1·2	1·3	3·4	3·8	4·1	1·8	2·0	2·2	19·8	21·8	23·7	4·9	5·3	5·7	24·6	27·1	29·5
1974	14·7	16·5	18·1	1·2	1·3	1·4	3·8	4·3	4·7	2·0	2·2	2·5	21·7	24·3	26·7	5·2	5·7	6·3	26·9	30·0	33·0
1975	16·1	18·3	20·3	1·2	1·4	1·6	4·2	4·8	5·3	2·2	2·5	2·8	23·8	27·0	30·0	5·5	6·2	6·9	29·3	33·2	36·9
1976	17·6	20·3	22·7	1·3	1·5	1·7	4·7	5·4	6·0	2·5	2·8	3·2	26·0	30·0	33·6	5·9	6·7	7·6	31·9	36·7	41·2
1977	19·2	22·5	25·4	1·4	1·6	1·8	5·2	6·1	6·8	2·7	3·2	3·6	28·5	33·4	37·6	6·3	7·2	8·3	34·8	40·6	45·9
1978	21·0	24·9	28·3	1·5	1·7	2·0	5·7	6·8	7·7	3·0	3·6	4·1	31·1	37·0	42·1	6·7	7·8	9·1	37·8	44·8	51·2
1979	22·9	27·6	31·6	1·5	1·8	2·1	6·2	7·5	8·6	3·4	4·1	4·7	34·0	41·1	47·0	7·1	8·4	9·9	41·2	49·5	56·9
1980	25·0	30·6	35·3	1·6	2·0	2·3	6·8	8·4	9·6	3·8	4·6	5·3	37·2	45·5	52·5	7·5	9·0	10·8	44·7	54·6	63·3
1981	27·3	33·9	39·3	1·7	2·1	2·4	7·5	9·3	10·8	4·2	5·2	6·0	40·6	50·4	58·6	8·0	9·7	11·8	48·6	60·1	70·3
1982	29·8	37·5	43·8	1·8	2·2	2·6	8·1	10·3	12·0	4·6	5·9	6·8	44·3	55·8	65·3	8·4	10·4	12·8	52·7	66·2	78·1
1983	32·4	41·5	48·9	1·8	2·4	2·8	8·9	11·4	13·4	5·2	6·6	7·8	48·3	61·8	72·8	8·9	11·2	13·9	57·3	72·9	86·7
1984	35·4	45·9	54·4	1·9	2·5	3·0	9·7	12·6	14·9	5·7	7·4	8·8	52·7	68·3	81·1	9·4	12·0	15·1	62·1	80·3	96·2
1985	38·5	50·7	60·6	2·0	2·7	3·2	10·6	13·9	16·6	6·3	8·4	10·0	57·4	75·6	90·3	9·9	12·8	16·4	67·4	88·4	106·7

Note: The above forecasts are based on the actual levels of traffic in each market in 1967.
Although trend values are preferable for long term forecasting currently available estimates display unresolved inconsistencies.

Table 2

Long term forecasts of demand for air transport movements at airports in the London area (currently Heathrow and Gatwick)
THOUSANDS

	Europe			**Irish Republic**			**North America**			**Other Long-Haul**			**Total International**			**Domestic**			**Total**		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (T)	142	142	142	14	14	14	23	23	23	17	17	17	196	196	196	54	54	54	250	250	250
1968	146	149	152	14	14	15	23	24	24	18	18	18	201	205	209	56	57	57	257	262	266
1969	151	156	162	14	15	16	24	25	26	18	18	19	207	214	222	58	60	61	265	274	283
1970	156	164	172	15	16	16	25	26	28	18	19	20	214	225	236	60	63	65	274	288	301
1971	161	172	183	15	16	17	25	27	29	18	20	21	220	234	250	62	66	69	282	300	319
1972	166	180	194	15	17	18	26	29	31	19	20	22	226	246	265	64	69	73	290	315	338
1973	171	189	205	16	17	19	27	30	33	19	21	23	233	257	280	66	72	78	299	329	358
1974	177	198	217	16	18	20	28	31	35	20	22	24	240	270	297	68	75	82	308	345	379
1975	183	208	230	16	19	21	29	33	37	20	23	26	248	282	313	70	78	87	318	360	400
1976	189	218	244	17	19	21	30	34	39	21	25	27	256	297	331	72	81	92	328	378	423
1977	195	229	258	17	20	22	31	36	41	22	26	29	265	310	349	73	84	97	338	394	446
1978	202	240	273	17	20	23	32	38	43	23	27	31	273	325	369	75	87	102	348	412	471
1979	209	252	288	17	21	24	32	40	45	24	29	33	283	341	389	76	90	107	359	431	496
1980	216	264	305	17	21	24	33	41	47	25	30	35	291	356	411	78	94	112	369	450	523
1981	223	277	322	17	22	25	34	43	49	26	32	37	301	374	434	79	97	117	380	470	551
1982	231	291	341	18	22	26	35	44	52	27	34	40	311	392	458	81	100	122	392	492	581
1983	239	306	360	18	23	27	36	46	55	28	36	43	321	411	484	82	103	128	404	513	612
1984	247	321	381	18	23	27	37	49	58	30	39	46	332	431	512	83	106	134	416	537	645
1985	256	337	403	18	24	28	38	51	61	31	41	49	344	452	541	85	109	139	428	561	680

Note: The above forecasts are based on estimated trend values in 1967.

Table 3

Short term forecasts of terminal passengers at airports in the London area (currently Heathrow and Gatwick)
MILLIONS

	Europe			**Irish Republic**			**North America**			**Other Long-Haul**			**Total International**			**Domestic**			**Total**		
		Most			Most			Most			Most			Most			Most			Most	
	Lower	Likely	Upper	Lower	Likely	Upper	Lower	Likely	Upper	Lower	Likely	Upper	Lower	Likely	Upper	Lower	Likely	Upper	Lower	Likely	Upper
1967 (Actual)	7·8	7·8	7·8	0·8	0·8	0·8	1·7	1·7	1·7	1·0	1·0	1·0	11·3	11·3	11·3	3·1	3·1	3·1	14·4	14·4	14·4
1968 (Prov.)	8·4	8·4	8·4	0·8	0·8	0·8	1·9	1·9	1·9	1·1	1·1	1·1	12·2	12·2	12·2	3·1	3·1	3·1	15·3	15·3	15·3
1969	9·1	9·5	9·7	0·9	0·9	0·9	2·1	2·2	2·2	1·2	1·2	1·3	13·3	13·7	14·1	3·2	3·4	3·5	16·5	17·1	17·6
1970	10·0	10·8	11·1	0·9	1·0	1·0	2·3	2·6	2·7	1·3	1·4	1·5	14·5	15·8	16·3	3·6	4·0	4·1	18·1	19·8	20·4
1971	11·0	12·0	12·8	1·0	1·1	1·1	2·6	3·0	3·1	1·5	1·6	1·7	16·1	17·7	18·7	3·9	4·5	4·7	20·0	22·2	23·4
1972	12·1	13·4	14·4	1·0	1·1	1·2	3·0	3·3	3·6	1·6	1·8	1·9	17·7	19·6	21·1	4·3	4·9	5·2	22·0	24·5	26·3
1973	13·3	14·9	16·2	1·1	1·2	1·3	3·4	3·8	4·1	1·8	2·0	2·2	19·6	21·9	23·8	4·7	5·3	5·7	24·3	27·2	29·5
1974	14·7	16·5	18·1	1·2	1·3	1·4	3·8	4·3	4·7	2·0	2·2	2·5	21·7	24·3	26·7	5·2	5·7	6·3	26·9	30·0	33·0
1975	16·1	18·3	20·3	1·2	1·4	1·6	4·2	4·8	5·3	2·2	2·5	2·8	23·7	27·0	30·0	5·5	6·2	6·9	29·2	33·2	36·9

Table 4

Short term forecasts of air transport movements at airports in the London area (currently Heathrow and Gatwick)
THOUSANDS

	Europe			Irish Republic			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (Actual)	149	149	149	14	14	14	22	22	22	17	17	17	202	202	202	57	57	57	259	259	259
1968 (Prov.)	154	154	154	16	16	16	24	24	24	18	18	18	212	212	212	55	55	55	267	267	267
1969	156	159	161	16	17	17	25	26	26	18	19	20	215	220	224	57	60	62	272	280	286
1970	158	167	170	16	17	17	25	27	28	19	20	21	218	231	236	60	67	69	277	297	306
1971	160	174	182	16	17	17	25	28	29	20	21	22	221	240	250	63	73	75	284	313	325
1972	163	180	194	16	17	18	26	29	31	20	21	22	225	247	265	68	77	80	293	324	345
1973	168	188	205	16	18	19	27	30	33	20	21	23	231	257	280	70	79	83	301	336	363
1974	176	198	217	16	18	20	28	31	35	20	22	24	240	269	296	72	80	86	312	349	382
1975	183	207	230	16	19	21	29	33	37	21	23	25	248	282	313	73	81	88	321	363	401

Table 5

Short term forecasts of terminal passengers at Heathrow
MILLIONS

	Europe			Irish Republic			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (Actual)	6·5	6·5	6·5	0·8	0·8	0·8	1·6	1·6	1·6	0·8	0·8	0·8	9·6	9·6	9·6	2·8	2·8	2·8	12·4	12·4	12·4
1968 (Prov.)	6·9	6·9	6·9	0·8	0·8	0·8	1·7	1·7	1·7	0·9	0·9	0·9	10·4	10·4	10·4	2·7	2·7	2·7	13·1	13·1	13·1
1969	7·4	7·7	7·9	0·9	0·9	0·9	1·9	2·0	2·1	1·0	1·0	1·1	11·2	11·6	12·0	2·9	3·1	3·2	14·1	14·6	15·1
1970	8·2	8·8	9·0	0·9	1·0	1·0	2·2	2·4	2·5	1·1	1·2	1·2	12·4	13·3	13·7	3·2	3·5	3·6	15·6	16·9	17·3
1971	9·0	9·7	10·2	1·0	1·1	1·1	2·4	2·7	2·9	1·2	1·3	1·4	13·6	14·8	15·6	3·5	4·0	4·2	17·1	18·8	19·8
1972	9·9	10·8	11·5	1·0	1·1	1·2	2·7	3·1	3·3	1·4	1·5	1·6	15·0	16·5	17·6	3·8	4·3	4·6	18·8	20·8	22·2
1973	10·8	11·9	12·8	1·1	1·2	1·3	3·1	3·5	3·8	1·5	1·7	1·8	16·5	18·3	19·7	4·2	4·7	5·1	20·7	23·0	24·8
1974	11·9	13·1	14·3	1·2	1·3	1·4	3·5	4·0	4·3	1·7	1·9	2·1	18·3	20·2	22·1	4·6	5·1	5·6	22·9	25·4	27·7
1975	12·9	14·4	15·8	1·2	1·4	1·6	3·9	4·5	4·9	1·9	2·1	2·4	19·9	22·4	24·7	5·0	5·5	6·2	24·9	28·0	30·9

Table 6

Short term forecasts of air transport movements at Heathrow
THOUSANDS

	Europe			**Irish Republic**			**North America**			**Other Long-Haul**			**Total International**			**Domestic**			**Total**		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (Actual)	125	125	125	14	14	14	21	21	21	15	15	15	175	175	175	46	46	46	221	221	221
1968 (Prov.)	130	130	130	16	16	16	23	23	23	16	16	16	184	184	184	44	44	44	229	229	229
1969	130	132	134	16	17	17	24	25	25	16	17	17	186	191	193	46	50	50	232	240	243
1970	131	139	141	16	17	17	24	26	26	17	17	18	188	199	202	49	55	56	236	253	259
1971	132	144	150	16	17	17	24	26	27	18	18	19	190	205	213	51	60	62	240	264	274
1972	134	148	159	16	17	18	25	27	29	18	18	19	193	210	225	55	63	65	247	273	289
1973	138	154	166	16	18	19	26	28	31	18	18	20	198	218	236	57	64	67	255	283	304
1974	145	162	174	16	18	20	27	29	33	18	19	21	205	228	248	58	65	70	264	293	318
1975	151	168	182	16	19	21	28	31	35	18	20	22	212	238	260	59	66	72	271	304	332

Table 7

Short term forecasts of terminal passengers at Gatwick
MILLIONS

	Europe			**North America**			**Other Long-Haul**			**Total International**			**Domestic**			**Total**		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (Actual)	1·4	1·4	1·4	0·1	0·1	0·1	0·2	0·2	0·2	1·6	1·6	1·6	0·3	0·3	0·3	2·0	2·0	2·0
1968 (Prov.)	1·5	1·5	1·5	0·1	0·1	0·1	0·2	0·2	0·2	1·8	1·8	1·8	0·3	0·3	0·3	2·1	2·1	2·1
1969	1·7	1·7	1·8	0·2	0·2	0·2	0·2	0·2	0·2	2·0	2·1	2·1	0·3	0·4	0·4	2·3	2·5	2·5
1970	1·8	2·0	2·3	0·2	0·2	0·2	0·2	0·2	0·2	2·1	2·4	2·7	0·4	0·4	0·4	2·5	2·9	3·1
1971	2·1	2·3	2·6	0·2	0·2	0·2	0·2	0·2	0·3	2·5	2·8	3·1	0·4	0·5	0·5	2·9	3·3	3·6
1972	2·2	2·6	2·9	0·2	0·3	0·3	0·3	0·3	0·3	2·7	3·2	3·5	0·5	0·5	0·6	3·2	3·7	4·1
1973	2·4	3·0	3·5	0·3	0·3	0·3	0·3	0·3	0·3	3·0	3·6	4·1	0·5	0·6	0·6	3·5	4·1	4·7
1974	2·8	3·4	3·8	0·3	0·3	0·4	0·3	0·4	0·4	3·4	4·1	4·6	0·6	0·6	0·7	4·0	4·7	5·3
1975	3·1	3·8	4·5	0·3	0·4	0·4	0·4	0·4	0·4	3·8	4·6	5·3	0·6	0·7	0·7	4·4	5·3	6·0

Table 8

Short term forecasts of air transport movements at Gatwick
THOUSANDS

	Europe			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1967 (Actual)	23	23	23	1	1	1	2	2	2	26	26	26	11	11	11	37	37	37
1968 (Prov.)	25	25	25	1	1	1	2	2	2	28	28	28	11	11	11	38	38	38
1969	26	27	27	1	1	1	2	2	3	29	30	31	11	11	12	40	41	43
1970	27	28	29	1	1	2	2	3	3	30	32	34	11	12	13	41	44	47
1971	28	30	32	1	2	2	2	3	3	31	35	37	12	13	14	43	48	51
1972	29	32	35	1	2	2	2	3	3	32	37	40	13	14	15	45	51	55
1973	30	34	39	1	2	2	2	3	3	34	39	44	13	15	16	47	54	60
1974	31	36	44	1	2	2	2	3	3	35	41	49	13	15	16	48	56	65
1975	32	39	48	1	2	2	3	3	3	36	44	53	14	15	17	50	59	69

Table 9

Estimates of typical daily demand for air transport movements at Heathrow on three representative days

	Europe			Irish Republic			North America			Other Long-Haul			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
Table 9a Day in August																		
1967	416	416	416	64	64	64	77	77	77	65	65	65	150	150	150	772	772	772
1970	432	461	467	70	76	79	87	93	96	73	74	78	159	176	181	821	880	901
1971	433	476	491	71	77	80	89	95	99	74	75	80	164	191	198	831	914	948
1972	439	486	520	72	79	82	91	98	104	75	77	82	173	200	207	850	940	995
1973	451	505	545	72	81	85	93	101	110	76	79	85	181	203	216	873	969	1041
1974	472	524	565	72	82	89	96	104	117	76	81	89	183	206	222	899	997	1082
1975	483	543	587	72	84	93	99	109	124	77	84	92	186	209	228	917	1029	1124
Table 9b Day in April																		
1967	339	339	339	41	41	41	54	54	54	68	68	68	138	138	138	640	640	640
1970	352	375	382	46	49	50	62	66	67	76	78	81	146	163	168	682	731	748
1971	355	388	402	46	50	51	63	68	70	77	80	84	152	177	184	693	763	791
1972	361	400	427	47	51	53	65	70	74	79	82	87	161	186	194	713	789	835
1973	374	417	449	47	52	56	67	72	79	80	84	91	169	192	203	737	817	878
1974	391	434	471	48	54	59	69	76	84	81	87	95	174	195	210	763	846	919
1975	405	453	494	48	56	62	71	80	89	82	91	99	177	198	215	783	878	959
Table 9c Day in January																		
1967	273	273	273	32	32	32	48	48	48	63	63	63	114	114	114	530	530	530
1970	278	298	303	35	37	38	54	57	58	71	72	75	118	132	136	556	596	610
1971	282	310	322	35	38	39	55	59	61	72	73	77	124	145	150	568	625	649
1972	290	320	343	36	40	41	57	61	65	73	75	80	132	154	159	588	650	688
1973	301	335	362	37	41	43	59	64	70	75	78	84	138	159	168	610	677	727
1974	317	352	384	38	42	45	61	67	74	76	81	88	143	142	174	635	704	765
1975	329	372	404	38	43	48	64	70	79	78	85	93	146	165	178	655	735	802

Table 10

Estimates of typical hourly demand for air transport movements at Heathrow on three representative days of 1975
(Based on most likely estimates)

Hour GMT	Day in August						Day in April						Day in January					
	Europe	Irish Republic	North America	Other Long-Haul	Domestic	Total	Europe	Irish Republic	North America	Other Long-Haul	Domestic	Total	Europe	Irish Republic	North America	Other Long-Haul	Domestic	Total
00.00–00.59	12	—	—	—	—	12	8	—	—	—	—	8	5	—	1	—	5	11
01.00–01.59	14	—	1	—	1	16	5	—	1	1	—	7	10	—	—	—	—	10
02.00–02.59	3	—	1	—	—	4	4	—	1	2	1	8	5	—	1	—	—	6
03.00–03.59	8	—	2	1	—	11	2	—	1	2	—	5	8	—	—	—	—	8
04.00–04.59	6	1	2	1	1	11	1	—	1	2	1	5	2	—	1	—	—	3
05.00–05.59	13	1	7	3	1	25	7	—	2	1	1	11	5	—	1	5	—	11
06.00–06.59	19	4	10	3	11	47	12	1	6	2	7	28	4	1	3	1	1	10
07.00–07.59	22	6	8	3	17	56	12	1	6	7	15	41	4	1	6	7	4	22
08.00–08.59	20	5	6	8	21	60	29	4	9	5	19	66	17	1	11	7	16	52
09.00–09.59	39	4	9	10	9	71	33	4	10	15	12	74	30	5	6	3	17	61
10.00–10.59	34	5	13	9	17	78	28	7	3	8	11	57	29	3	3	3	11	49
11.00–11.59	33	2	7	3	9	54	34	1	7	3	8	53	23	3	6	5	11	48
12.00–12.59	30	4	16	6	6	62	34	4	6	2	7	53	27	3	6	8	8	52
13.00–13.59	32	6	9	2	3	52	27	3	4	3	8	45	21	3	3	8	2	37
14.00–14.59	25	3	8	6	11	53	30	3	7	3	9	52	26	1	5	3	8	43
15.00–15.59	27	6	1	4	12	50	28	4	4	8	16	60	26	2	8	10	8	54
16.00–16.59	32	5	2	7	15	61	32	4	3	5	9	53	31	5	3	2	5	46
17.00–17.59	37	5	1	3	17	63	22	3	1	3	16	45	22	5	—	8	8	43
18.00–18.59	27	5	1	4	14	51	29	2	—	5	15	51	25	1	3	2	18	49
19.00–19.59	27	5	1	6	17	56	18	4	—	5	17	44	19	2	—	5	12	38
20.00–20.59	23	4	—	1	4	32	16	4	3	5	8	36	10	3	—	3	18	34
21.00–21.59	28	3	4	3	9	47	25	1	1	2	4	33	9	3	3	2	6	23
22.00–22.59	22	5	—	—	8	35	14	6	4	2	7	33	9	—	—	3	4	16
23.00–23.59	10	5	—	1	6	22	3	—	—	—	7	10	5	1	—	—	3	9
Totals	543	84	109	84	209	1,029	453	56	80	91	198	878	372	43	70	85	165	735

APPENDIX 2

Report of the DC(P) Working Party on the ATC capacities of Heathrow and Gatwick airports

Constitution of the Working Party

1. The Working Party was appointed in April 1968 by the Controller, NATCS to provide CA3 Working Party with estimates of the ATC capacities of Heathrow and Gatwick Airports until at least 1976. The DC(P) Working Party was required to produce papers showing in detail the facts, assumptions and logic behind the estimates. Membership included representatives of BEA, BOAC, DORA, DCO, DCATO, DLM, D Tels ATC, BAA and DC(P). Members of the CTLA Secretariat attended later meetings. DC(P) delegated the chairmanship to DDCPI.

Scope of operation

2. The area under consideration was limited in the case of arriving aircraft to the phase of flight from the beginning of intermediate approach to the point of exit from the runway and, for departing aircraft, from the time the aircraft is ready to leave the apron until it is handed over to the London Air Traffic Control Centre. Ground Movement Control is to be the subject of a separate study.

Estimation of capacity

3. When the traffic demand exceeds the capacity of the ATC system the traffic is obliged to queue and incur delay; the extent of the delay being dependent upon the volume of the demand in relation to the capacity and also the distribution and characteristics of the demand. A method of studying the relation between demand and delay under a variety of operational conditions was required to assess the limiting capacity of the ATC system and the pattern of delays associated with a particular demand.

4. Mathematical queueing theory can give a measure of the capacity of the ATC system if the system can be simplified and defined in general terms. However, because the performance is so dependent upon the instantaneous nature of the demand and the exact sequence of events which precede it, a simulation model of the system was considered likely to produce better answers. This type of model has the advantage that a number of different operational modes can be contained within the one model and the effect of a variety of different ATC procedures assessed directly in some considerable detail.

5. A model of this type was under development within DORA (then AORB) as a fast time aid to the study of ATC systems, and this appeared to hold an immediate prospect of achieving suitable results. Although the model was of considerable complexity and required further time to finish its development, those concerned were confident its use would represent a major advance in the study of ATC systems.

6. The estimation of the capacity of an ATC system is a complex subject as it involves not only the measurement of the ability of a system to deal with movements under the conditions of a specific demand but also the specification of capacity in a form which takes account of the full interplay of variables within the system. For this purpose the concept of a 'runway service (acceptance) rate' was introduced and this was defined as the mean movement rate achieved when queues do not dissipate, i.e. when the demand is such that aircraft are available at all times to use the runway. This therefore constitutes the maximum utilisation of the runway and as performance varies from movement to movement the mean value is quoted as the average capacity of the system.

7. At its first meeting the Working Party decided to make use of the DORA model in view of its advanced state of development.

The fast time simulation model

8. A general description of the model is given in Annex A of this Report. The model is designed to represent that portion of the ATC system concerned with utilisation of the runway(s) by reproducing the operational sequences, the ATC rules and procedures and the performance standards of a real life system or one which can be postulated in these terms.

9. Aircraft enter the model at the TMA boundary or at 'Start UP' and leave it when turning off the runway or when airborne. The associated airspace is not simulated explicitly but the effect of congestion or delay in this area is implicit in the model. For instance no attempt is made to differentiate between aircraft stacked, short routed or delayed by deviation from the direct flight path.

10. The model does not attempt to simulate the problems of interaction between traffic at different aerodromes since such interaction occurs outside the area under consideration, nor does it deal with the taxiway system.

The inputs to the model are:

(a) The ATC rules and procedures.

(b) The controllers' performance and behaviour. (In terms of time distributions for each function.)

(c) The aircraft/pilot performance and behaviour.

11. Provision has been made for the model to work in any of the following modes:

(a) Segregated departures and arrivals.

(b) Mixed departures and arrivals.

(c) Dynamic admixture of both.

The dynamic mode assesses the impending demand on the system and switches the mode of operation to service the maximum number of movements. Results with this mode have not been included as further development is required of the rules governing this mode of operation.

12. The model prints out the life histories of all aircraft processed so that their progress can be studied and anomalous behaviour noted. It also produces data associated with each run from which particular performance statistics can be plotted and studied.

Test and validation of the model

13. Validation of the model was carried out by comparing its performance with that of the ATC system in operation at Heathrow. After the current ATC rules and operational values for Heathrow had been programmed, a series of runs was carried out simulating the same demand upon the system as that to which Heathrow had been subjected and on which a sample of observations had been collected during the summer of 1968. This sample had been carefully checked to ensure that it did not include observations on traffic behaviour attributable to elements outside the ATC system or the area of the model. The sample consisted of observations on four days of operations at Heathrow on which segregated landings and take-offs used separate parallel runways.

14. A meeting was held at which the results of the test were presented and explained. It was considered that good correlation had been achieved between the model output and the Heathrow observations and the Working Party therefore endorsed the further use and development of the model.

Reprogramming of the model for forecasting purposes

15. The input parameters of the model had been arranged to simulate current operational performance of the ATC system at Heathrow for purpose of validation. It was then necessary to modify the input parameters in order to simulate the ATC performance of the system during the period under consideration by the CA3 Working Party. A Working Group including BEA, BOAC, DORA, BAA and a cross section of NATCS was set up for this purpose and as a result of their meetings DORA was advised of the parameter values to be used in the model in order to reproduce the system performance expected by the mid 1970s. A description of the sub group's work and its recommendations are contained in Annex B.

Simulation exercises

16. The model was run to simulate ATC operations at Heathrow using traffic samples provided by the CA3 Working Party for the 15th busiest day in each of the years 1974, 1976 and 1978. Each simulation was run ten times to provide a distribution of delays. The results were analysed to establish the system performance in terms of delays arising from the traffic demand. The maximum acceptance rates on the runway were

determined by preliminary tests on the model. The traffic samples were then 'idealised' and constrained to 90 per cent of maximum acceptance rate. In doing this the movements displaced from the peak hours were accommodated in adjacent hours. This provided an indication of system reaction to a smoother traffic demand. Both 'segregated' and 'mixed' modes of runway operation were simulated.

17. In the time available it was not possible to simulate Gatwick operation. The model will need to be carefully reviewed and may require adaptation for this purpose.

18. Results of the runs are contained in Annex C.

Discussion of results

19. Before discussing the results in detail it is necessary to record the Working Party's views on the validity of the simulation exercises. It is the opinion of the Working Party that the model reproduced in a satisfactory manner both modes of runway operation as they were previously defined. However, in the opinion of the Working Party, the model needs to be further developed to simulate a more flexible form of 'mixed' parallel operations than is currently possible. Most but not all members of the Working Group considered that the values allotted to inter-arrival intervals in this mode were generous. Further development and re-programming of the model is considered to be a prerequisite to adequate simulation of mixed operations and the Working Party recommends that the model outputs so far obtained for the mixed mode of operations be regarded as provisional. The results indicated the value of the model in providing a realistic means of determining a service rate (maximum runway acceptable rate) appropriate to the model parameters. It further indicates that when the demand lies in an area some 10 per cent below this rate the delay is stabilised.

20. With the parameter values and the traffic samples used in the fast time simulation the model indicated a service rate of 38 landings and 46 take-offs an hour. By limiting the demand to 90 per cent of these figures the average delay stabilised at 5 minutes. As the level of demand increased beyond 90 per cent the delay stabilised at a much higher figure and, above 100 per cent delays increased steeply and became a function of the period for which this persisted. The effect on the delay pattern of using uninhibited demands is illustrated in Graphs 9a and 11a in Annex C.

21. As an example the table below shows the position with the 1978 'most likely' forecast of arrivals in the segregated mode and compares the delays arising from unconstrained demand with the results of restricting the maximum demand to 90 per cent of the service rate by traffic management

Unconstrained Demand		**Demand at 90 per cent of Service Rate**	
Mean delay	90 per cent Probability delay	Mean delay	90 per cent Probability delay
17 mins	27 mins	5 mins	11 mins
(See Fig. 6, Annex C)		(See Fig. 8, Annex C)	

and accommodating the excess demand in the less busy hours. The table shows the mean delay together with the maximum delay which might be experienced by 90 per cent of the traffic over the busy three hour period.

There is of course a limit, to be defined by the airline operators, to the amount of re-scheduling that can be achieved at Heathrow. It is also necessary to define the amount of delay that can be tolerated. When these two quantities have been determined it should be possible to read from the output of the model the capacity of Heathrow to meet future demand.

22. It should be noted from graphs 4a and 4b of Annex C that the delays arising from the traffic demand and service rate are extremely sensitive to the parameter values. It will be seen that there is a similarity between the average delays for 1969 based on present standards with the delays forecast for 1974 based on assumed system performance. A study of results in the mixed mode shows that departures are subject to an increased delay and arrivals to less delay and that the situation is not materially better than under segregated working. Subsequently it was considered that the rules governing the mixed mode of operation might be too rigid and a more flexible mode should be examined. It was considered that in practice, in the 1970s, the rigid mixed operation would be replaced by a more flexible 'dynamic' ATC system making tactical use of parallel runways to meet peaks of inbound and outbound traffic, as mentioned in para. 11 above.

Extraneous influences

23. It should be noted that there are other factors not appropriate to the ATC simulation work done which could modify the figures given in para. 21. These include:

minimum noise routeings
aircraft operating procedures
pilot techniques
revised turbulent wake criteria
development of the area south of runway 28L
category II and III operations
ground movement control
acceptable overshoot rates
airspace constraints.

Factors which may tend to improve the figures include:

pressure of demand
improved facilities
better techniques.

Conclusions

24. Meaningful estimates of ATC capacity have to be expressed in terms of delay to the traffic concerned. It is therefore necessary to produce as positive a method as possible of relating the demand pattern to a delay distribution.

25. The fast time simulation model developed for this purpose is in its present form capable of achieving a realistic simulation of segregated runway operations at an airport.

26. The results indicate that Heathrow is capable of meeting the most likely forecast demand for the 15th busiest day in:

(a) 1974 with an average delay of about five minutes;

(b) 1978 with an average delay of the same order provided that the demand is limited to 90 per cent of the service rate.

27. Limiting the demand to 90 per cent of the service rate in 1978 entails the transfer of 38 movements from the peak period of the day at Heathrow.

28. The mixed parallel mode of operation has not given the expected performance improvement and it is considered that the rules governing operation in this mode should be examined to obtain a better measure of its potential at Heathrow.

29. The delay distribution is shown to be sensitive to:

(a) small changes in service intervals;

(b) limiting of demand to a level around 90 per cent of the service rate level;

(c) limiting of demand within the hour to achieve a more uniform demand.

30. The output of this model has been most useful in proving its potential value as a means of estimating ATC delays at Heathrow and also for understanding the significance of the different factors operating in ATC at a multi-runway airport.

Recommendations

31. The Working Party recommends that:

(a) further work be done by DC(P) and DORA in consultation with the other interests represented on the Working Party to develop the model for further simulation work on ‘mixed’ modes of operation;

(b) further consideration be given in the light of changed standards to updating the time distributions in the model;

(c) in due course operations at Gatwick be simulated for the purpose of updating the ATC capacity forecasts;

(d) consideration be given to extending the area covered by the model so as to include (i) interaction between Heathrow, Gatwick and Luton traffic and (ii) other ATC processes beyond airports and TMAs;

(e) the results so far obtained be used for present purposes but, because assumptions in the model may undergo change as a result of the action recommended in (a) and (b) above, the CA3 Working Party should be prepared to review its findings from time to time.

APPENDIX 2 ANNEX A

Brief notes on a computer simulation model to be used for the estimation of the ATC capacity of an airport

(Prepared for DC(P) Working Party on airport capacity June 1968)

Introduction

For the operation of this model, not one computer programme is required but four, one for each of the four parts of the simulation system. The general organisation of the system is shown on the attached main diagram. The simulation unit contains the main programme. The service rate unit together with the traffic generation unit provide the simulation unit with information on the nature of the traffic demand on the airport and the traffic handling capabilities of the runway system at the airport. The other local input to the simulation unit controls the internal operation of the programme within this unit. A nominal amount of statistical analysis for preliminary checking purposes is carried out within the simulation unit; in the main, the raw output data from simulation is fed to a separate analysis unit for reduction to a meaningful and digestible form. Each of the units of the system is entirely self contained and may be run at quite different times on the computer.

The model is essentially an airport model, and assumes no restriction to movement within the airspace around the airport, except outbound radar separation between successive departures following the same track within the TMA, and the separation between arrivals in the approach phase. Restrictions on the ground related to flight-level occupancy en-route are not simulated. The interaction between airports such as Heathrow and Gatwick where movements to or from one of the pair may affect the capacity of the other has not been included in the present model. This problem is being considered, however, and as a first stage, the output from the present model is being arranged to produce the patterns of flow crossing those points within the TMA that are common to the routes associated with both Heathrow and Gatwick.

Although the model is primarily for application to Heathrow or Gatwick Airport, a wider degree of flexibility is available within the model to extend study to other more complex runway configurations. Any airport layout may be studied provided that it can be considered as being made up of one or two independent runway modules. A runway module may take one of two forms:

(a) single runway;

(b) close parallel runways.

Intersecting runways and closed vee runways may be considered as special cases of (b), open vee runways as a special case of (a).

It is essential in the model that use of the runway concrete on one module does not interact with that on the other module of a two module airport.

To allow for runway direction changes to the reverse direction on a two module airport, the model can cater for up to four departure holding points and four final approach paths.

Apart from the estimation of capacity, the model has also been designed to fulfil a requirement for a tool with which to study the effect and benefits that may accrue from various levels of traffic flow planning and the strategic use of runways at a multi-runway airport. For this reason, information is used within the model that relates to the en-route phase of flight inbound, as well as advance information on departures before request for engine start-up clearance is made. Such facilities within the model subsume a degree of sophistication of operation that does not exist yet within the real life system. For this reason, the design of the model has incorporated a method of programme control that may be used to set the degree of sophistication of the strategic use of runways.

The simulation model is being written in Control and Simulation Language (CSL) for running on an ICT 1900 series computer.

2. The service rate unit

This unit deals with the two types of modules, and, given information on the mean and spread of component process times, will give the average number of departures and arrivals that may use each module in unit time during those occasions when each movement on the module has been delayed from using the module due to the presence of the preceding movement.

For any given module and list of runway processing times, the unit produces an output covering a list of strategies of use of the module. These strategies are:

- Arrivals only
- One departure between successive arrivals
- Two departures between successive arrivals
- Three departures between successive arrivals
- Departures only

The unit provides an input to the planning element of the simulation which requires information on the number of departures and arrivals that can be expected to be handled on the runways of the airport, for any prospective strategy or mixture of strategies for using the airport runway facilities.

Two examples of how the component processes on the runway are handled within the service rate unit are shown in the second diagram. The strategy shown is one of alternate arrivals and departures operating on a single runway module in one case, and on a 'close parallels' module in the other. The significant differences in operation between the two types of modules which could lead to an increased service rate on the 'close parallels' can be clearly seen. In the 'close parallels' case there is much more likelihood of a departure having lined up and being ready to roll at the time that the runway becomes available with reference to the position of the preceding arrival. In the diagram of single runway operation, it has been assumed that the earliest time a departure may start to roll is when the preceding arrival is clear of the runway. In the 'close parallels' case, the departure is assumed to be clear for take-off when the preceding arrival touches down, and that the departure should be at least some 9,000 ft down the runway when the following arrival has reached an assumed committal height of 200 ft. This restriction imposes a minimum separation of 2 miles between the departure and the arrival when the runway thresholds are adjacent to each other. All these assumptions have been constructed purely for the purposes of the example. They are by no means rigid within the operation of the simulation system since they can be readily changed, as can the levels of slickness of operation on the runway and the degree of precision of final approach control, by alteration of the local inputs to the service rate unit.

A fuller description of the analyses involved within the service rate unit is given in Working Paper 73 of the 17th IATA Technical Conference, Lucerne, 1967.

3. The traffic generation unit

This unit takes as its main input a scheduled pattern of demand. The elements of information within the schedule are as follows:

(1) Arrival or departure.

(2) Route (i.e. airway).

(3) Speed group.

(4) Scheduled time of arrival or departure.

Speed groups are as follows:

(1) Jets.

(2) Large turbo-props.

(3) Other turbo-props, piston.

(4) Small piston.

Each arrival enters the simulation model at the time that a forward estimate is given either for the FIR boundary or for the first inbound reporting point within the airway. Flight down the airway to the TMA boundary is simulated and as the flight progresses into and down the airway, a set of forward estimates of the times that arrivals will desire to land is developed and updated. In this way, the planning element within the simulation unit gains advance information on the level and geographical distribution of impending traffic demand. This is purely an early warning device—higher level planning by means of requests for speed changes within the airways to alter the pattern of traffic entering the TMA has not been included in the model.

For departures, a warning time has been postulated approximately thirty minutes before each departure would desire to taxi from the stands. At the warning time, a departure enters the simulation model. From the warning time through to the time of actually being given taxi clearance, a forward estimate is developed and updated of the time that each departure will desire to use the runway facilities.

The output from this unit gives the forward estimates of demand on the airport, and this together with the output from the service rate unit, forms the total input to the planning element within the simulation unit.

4. The simulation unit

4.1 *The method of simulation*

4.1.1 The method of operating the airport simulation is, in essence, quite simple, but it does affect the approach taken to the problem and some understanding of it is therefore desirable.

We consider a sequence of aircraft entering the system. Each aircraft has associated with it the time of the next event in which it participates. These events are the activities which can affect the aircraft. The simulation examines the list of times and selects the earliest one (indicating the next event to occur). The simulation time is then advanced to this point and all the activities are examined in turn to see if they can be carried out. (Note that this method covers the case of simultaneous events.)

4.1.2 Examples of activities which can involve aircraft directly are:

> *Entry to the system:* This determines whether the movement is an arrival or departure and sets the aircraft into the correct stream of events, and also determines when the next aircraft enters.
> *Update arrival:* This provides the equivalent of an airways position report and finally transfers the aircraft from the airways system to the TMA.
> *Finals:* This activity effectively gives control inside the TMA, including stacking and sequencing on a first come, first served basis, onto final approach.
> *Arrival:* This activity takes over at the point where an aircraft is committed to land and determines whether an overshoot is necessary and if not, the time for which the runway is occupied by the arrival.
> *Request start-up:* This activity determines whether clearance to start can be given according to the rules, and if so, when the taxi clearance request will be made.
> *Taxi clearance:* This activity gives taxi clearance if possible, assigning the aircraft to a runway and determines when the aircraft arrives at the holding point.

Other activities clear each departure to line-up on the runway, clear departures to take-off, activate the planning element and indicate a forthcoming runway direction change.

4.2 *The planning element*

The planning element assesses the nature of the impending traffic demand on the airport, together with the traffic already waiting to use the runways, and compares this with the service rate of the runway facilities of the airport, testing each of the available strategies of use of the runways in turn. This process is carried out at the beginning of each planning period and the 'best' strategy is chosen and stored for use during the period ahead that lies between one planning period and two planning periods hence. For instance, if the planning period is chosen to be 15 minutes, then at, say, 10.00 hours, the planning element defines the runway strategy for use during the period 10.15 to 10.30 hours.

In the present planning element, the 'best' strategy is defined as that which is expected to leave a minimum residue of traffic demanding use of the airport and not being able to do so, or, in the event of several strategies producing zero residue, the first zero residue strategy is chosen. Residual arrivals may be given a greater weighting than residual departures to account for priority of use of the runway system at the airport by arrivals. By judicious choice of the order in which these strategies are presented to the planning element, control of the operation of the model can be effected such that the modes of using the runways can be examined within the model in any preference order. For example, at Heathrow, by this means it is possible to simulate operations of the runways in a segregated arrival/departure mode when traffic demand is light, and to graduate automatically to parallel arrivals and departures during peak times of the day, if this mode should prove to have higher handling capacity.

This design of planning element has been developed at this early stage to ensure that the traffic and runway information both input and generated within the model is sufficiently comprehensive to support insertion of strategic planning of high sophistication. The present planning element is not intended to represent a final solution. It has been introduced as a basis for discussion from which, it is hoped, the formulation of an agreed and practically tenable representation of strategic planning and tactical control will emerge. The planning element section of the simulation programme may be readily inserted, extracted or replaced.

Initial runs on the model for Heathrow will concentrate on a system with no dynamic planning but with a facility to change the mode of operation from segregated arrivals and departures to parallel arrival and departure operation during periods of the day specified within the list of control inputs to the model.

4.3 *The arrival process*

Arrivals enter the TMA, and provided that there is no arrival queue ahead, each arrival proceeds to its landing runway as defined by the planning element. By definition, for those arrivals that are undelayed in the TMA, the actual times of using the runways and the time of desiring to use the runways are coincident. For those arrivals that cannot use the runways at this time due to the existence of an arrival queue, the delay suffered is measured as the difference between the time of desiring to land and the time of actually landing.

When arrivals are queueing for the use of the runway facilities, the rates of output from the queues to the runways are controlled in accordance with the current strategy as defined by the planning element. The locations of stacks, the nature of intermediate approach paths, and the final turn distances from the thresholds of the landing runways are not explicitly input or generated within the simulation programme. In essence a period of time is allowed to elapse after an arrival has entered the TMA. This period represents the time that the arrival would take to fly from the transfer point to the runway threshold provided that there was no other arriving traffic immediately ahead and proceeding to the same landing runway. At the end of this period, if the arrival ahead has not already completed use of the landing runway, the arrival being considered enters the arrival queue associated with this runway within the model to await its turn. The delay experienced in this queue during simulation is intended to represent the effect of path stretching or holding in the stacks or a mixture of both forms of delay in the operational system.

Allowances have been made to accommodate the natural inertia that exists in the approach control process. If a change of strategy is indicated by the planning element which requires a change in the number of runways accepting arrivals or a change in the inter-arrival interval to an arrival runway, then only those arrivals that are greater than some 20 nautical miles flying distance from the arrival thresholds can respond to the requirements of the new strategy.

Any arrival that reaches a height of approximately 200 ft before the landing runway is defined to be clear with respect to the preceding movement is simulated to overshoot and to go round and rejoin the arrival stream again, following the latest aircraft that has been committed to using the runway.

4.4 *The departure process*

When a departing aircraft requests engine start-up clearance, a review is made of the traffic situation in the departure holding points, the taxying phase, and on the stands, together with the current and future strategies of operation on the runways. Start-up clearance will not be given if the contents of the holding points are nearing saturation or if there are already aircraft delayed on the stands. At its highest level, this flow planning process on the stands is rather more complex than that currently carried out in the present system at Heathrow. A facility for down-grading the process within the model to a mode of operation approximating the current real life methods has been included within the list of control parameters to the programme.

No detailed aspects of the taxying phase have been included. A distribution of taxi times to each of the four holding points is available to the programme, and arrival at a holding point is generated by sampling from the relevant taxi time distribution and adding this to the time of start of taxi.

Within each holding point, some reshuffling is permitted so that the most advantageous sequence of departures is fed to the runway, taking due account of outbound radar separations, the contents of the other holding points, and the runway strategy presently in use. Before any departure is cleared to leave the holding point, a check is made to ensure that it is likely to be clear before the next arrival, if any, will require to use the same runway.

4.5 *Runway direction changes*

The times of runway direction changes through 180 degrees on both runway modules of the airport may be input with the list of programme control parameters. As soon as a runway direction change is imminent, the flow planning mechanism related to the departure stands starts to feed departures to one or both of the holding points associated with the new direction.

Those arrivals that are already within 20 nautical miles flying distance of the arrival threshold(s) land in the old direction. Those departures that have already taxied from the stands also take-off in the old direction.

No arrival may land and no departure may take-off in the new direction until adequate separation has been achieved with the last departure and the last arrival using the runways in the old direction.

4.6 *Closure of runways*

Consideration is being given to simulating total and partial close-down of the runway facilities. Further discussion will be necessary on the ways in which these conditions are handled in the real-life system before progress can be made in this area.

4.7 *Output*

The output from the simulation unit will be the life history of each movement that has been simulated to use the airport. This will take the form of a series of times that significant events occurred to each movement. The list is as follows:

Arrivals

1. Route.
2. Speed Group.
3. Position in schedule.
4. Scheduled time of arrival.
5. Landing runway.
6. Time of entering system.
7. Time at 1st en-route reporting point.
8. Time of entry to TMA.
9. Time of desired approach to threshold (if undelayed).
10. Time of actual approach to threshold.
11. Whether overshot.
12. Actual time of crossing threshold.
13. Actual time of touchdown.
14. Actual time of clearing runway.

Departures

1. Route.
2. Speed Group.
3. Position in schedule.
4. Scheduled time of departure.
5. Time of entering system.
6. Time of request for engine start-up clearance.
7. Time of issue of engine start-up clearance.
8. Time of arrival at holding point.
9. Location of holding point.
10. Number of times overtaken in holding point.
11. Time of clearance to leave holding point.
12. Time of lining-up on runway.
13. Time of start to roll.
14. Time airborne.
15. Time of turn from C/L of runway.
16. Times at points within TMA before transfer point after airborne.
17. Time at transfer point.

These life histories form the input to the analysis unit.

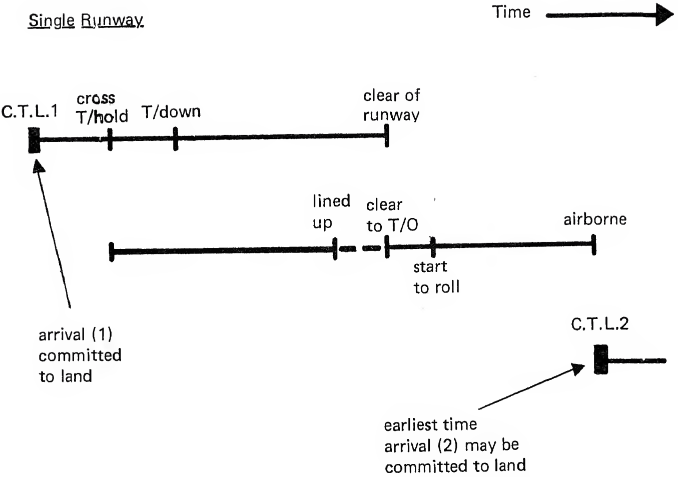
5. The analysis unit

This programme has been developed for general use in simulation studies from an original programme written for computer analysis of data collected during AORB/ATC field studies.

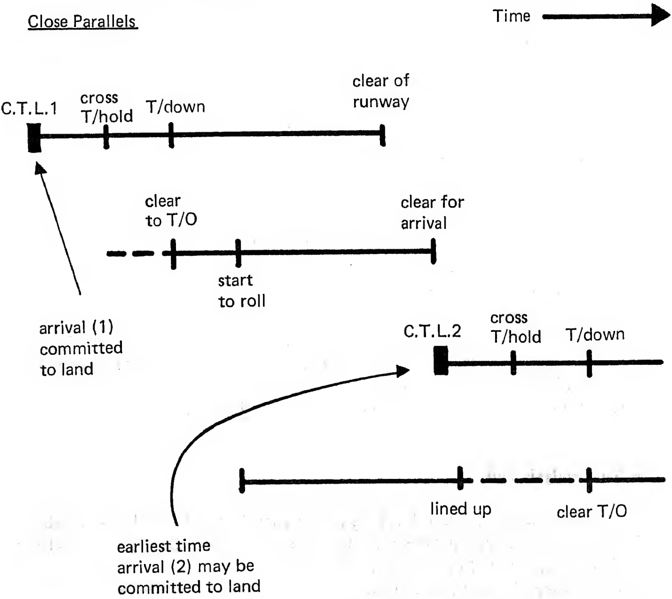
The nature of the statistics that can be produced may be gleaned from an examination of previous OR notes on ATC studies. Briefly, such statistics cover histograms of (a) delays experienced at selected points in the

Interaction of Runway Process Times

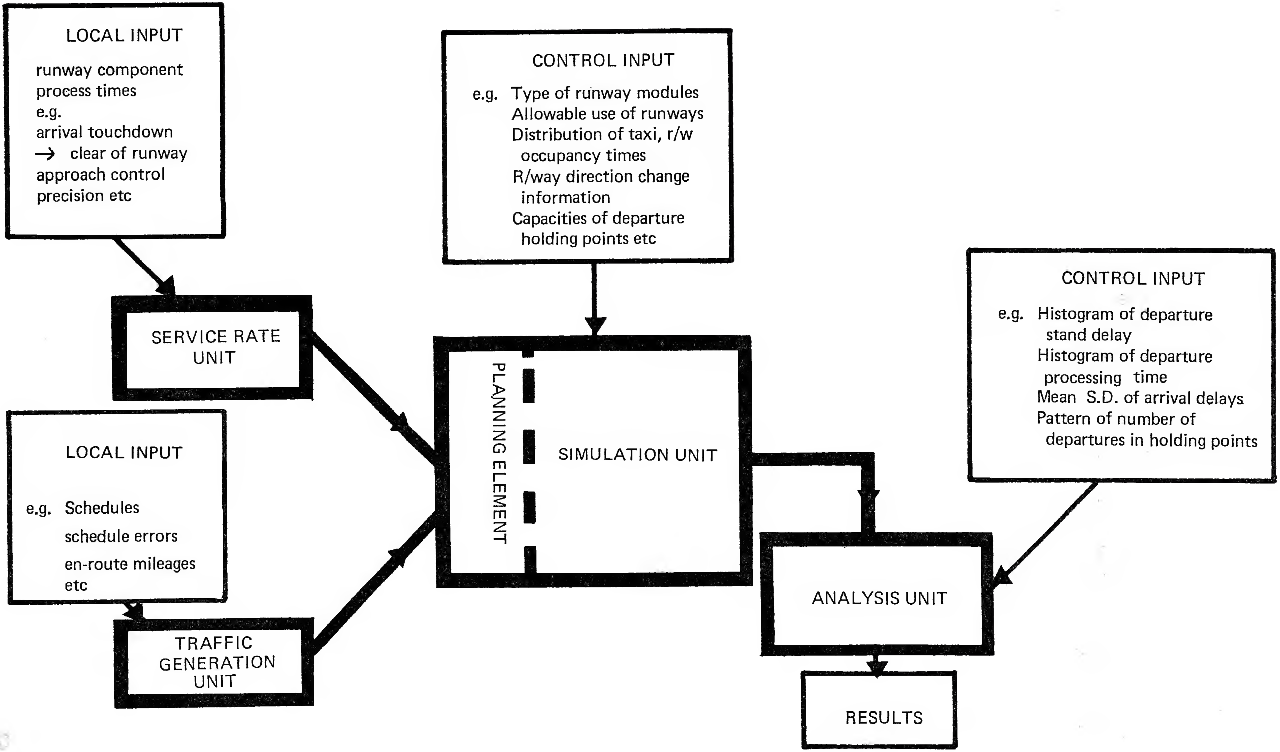
Single Runway



Close Parallels



General Organisation of the Simulation System


LOCAL INPUT
runway component process times
e.g.
arrival touchdown → clear of runway
approach control precision etc
SERVICE RATE UNIT
LOCAL INPUT
e.g. Schedules
schedule errors
en-route mileages etc
TRAFFIC GENERATION UNIT
CONTROL INPUT
e.g. Type of runway modules
Allowable use of runways
Distribution of taxi, r/w occupancy times
R/way direction change information
Capacities of departure holding points etc
PLANNING ELEMENT
SIMULATION UNIT
CONTROL INPUT
e.g. Histogram of departure stand delay
Histogram of departure processing time
Mean S.D. of arrival delays
Pattern of number of departures in holding points
ANALYSIS UNIT
RESULTS

departure or arrival processes or (b) the number of aircraft in specified queues or (c) the time interval between successive movements on a selected runway; the computation of average values and standard deviations; and the time pattern of delays, processing times, or the number of aircraft at a location throughout the simulated period.

The simulation system is, therefore, capable of producing any statistic within a wide range, and the output from just one simulation run may be progressively analysed by a repeated application of the analysis unit programme.

Note on the work carried out by a working group appointed to advise on the assumptions and parameters to be fed into the model

1. The Group was appointed to advise DORA on:

(a) The ATC rules and procedures to be simulated.

(b) The time distributions to be related to the various ATC operations incorporated in the model.

2. Two meetings were held to provide the information required at (a). Three meetings were held to provide the information required at (b). The revision of the time distributions and the reasons for the changes are shown in the following paragraphs:

Inter-arrival intervals

3. Taking into account current American practices (whereby average movement rates on an arrival runway during busy hours are about 5 or 6 an hour above those achieved at Heathrow) and acknowledging that there seems to be a certain amount of slack still to be taken up in the Heathrow landing operations, it was arbitrarily agreed that a reduction of 15 seconds in the mean value could reasonably be inserted. The Working Group was conscious of the fact that the United States' performance was associated with, inter alia, generally better weather conditions and potentially higher incident rates than those experienced at Heathrow and was of the opinion that the reduction proposed should be taken in the landing context and the assumed visual airport weather conditions and dry runways expected to prevail in the summer periods in which the peak demand simulated would occur at Heathrow. It was accepted that a reduction in the spread of inter-arrivals would be necessary if the overshoot rate was to be kept within limits. It was considered that the model might produce more overshoots than occurred in practice because it was not possible at this early stage to make all the tactical assessments of which the pilot/controller combination is capable. It was agreed that as overshoots in practice due to infringements of minimum runway separation criteria occurred only infrequently, (·05 per cent of occasions in the 1969 summer period) they should be ignored in the model provided that the interaction between runway occupancy times and inter-arrival intervals was maintained in the model as in real life. It was understood that further reduction of the landing interval might be achieved if an element of automation could effectively be introduced in the intermediate approach sequencing area. Such a system is in the course of feasibility study and development but it was considered too premature to anticipate any benefits that might accrue from it.

Inter-departure intervals

4. In considering future possibilities, the Working Group took account of the procedures expected to be used in the Mediator era to expedite take-off clearance. The Working Group noted that similar procedures had been in use for some time; they appeared to be working effectively and were expected to become more efficient as greater use was made of the western extension to the TMA and the Mediator system settled down. The Group was aware of the possibility of further restraints on outbound clearances that might be imposed by more restrictive noise routeing in the

future, but as they could not be predicted, no account of them would be taken by rule-changing in the model.

5. It was decided that at the present stage the following mean time intervals should be inserted to represent mid-1970s performance:

(a) one minute between departures on divergent routes;

(b) 75 seconds between departures on the same route.

It was pointed out by DORA that the specification of a single mean interval to cover all combinations of fast and slow aircraft along the same route prevented the model showing the probable effect of different types and route mixes on the hourly delay figures. It was subsequently found that the programming of the above intervals did not significantly alter the departure service rate nor the delay picture from that when the rules in (b) were:

(i) Fast after slow on same route 3 minutes.

(ii) Fast after fast or slow after slow on same route 2 minutes.

(iii) Slow after fast on same route 1 minute.

Therefore the runs were conducted with the separate intervals as specified above.

Departure–arrival intervals mixed mode of operation

6. The forecasting of future distributions and time intervals between arrivals to permit interleaved departures on the same runway was rendered difficult by the limited experience of this type of operation at Heathrow when two runways are in use and the consequently small sample of observational data available. It was decided to proceed cautiously and to propose a reduction of the mean interval between successive landings, when separated by an intermediate departure, by only 10 seconds to 170 seconds. The Group wished to record, however, that this figure compared most unfavourably with American practice and might prove to be unduly conservative. Where intervals are excessively large two or more departures would be sequenced between consecutive arrivals.

Runway occupancy time (arrivals)

7. It was decided to reduce the mean runway occupancy time programmed for arrivals from 55 to 50 seconds because it was thought that the proportion of propeller and prop jet aircraft would fall and there would be an improvement in slickness on the runway. It was further decided in view of the recent changes in arrival clearance procedures, whereby in suitable conditions of visibility two aircraft are now authorised to occupy the same runway, that clearance might be anticipated by up to 10 seconds by the controller and that account of this should be taken in the model programme.

Runway occupancy time (departures)

8. In the case of departures it was at first thought that no changes would be specified, runway occupancy time to lift off being on the average less than the interval required between successive departures for en-route clearance. However it was subsequently shown from the initial runs that with the time distribution of aircraft moving from the holding point onto the runway and the subsequent clearance of the runway after take-off the

en-route intervals could be exceeded. The model output indicated that the holding point to line-up times after a departure and the definition of airfield clearance were factors which could materially influence the departure service rate.

9. The Working Group considered there was a good deal of slack in this phase of operation at Heathrow owing to the comparatively low pressure of demand and felt justified in assuming that (a) the faster times experienced when an aircraft lines up before an arrival would be achieved in the future and (b) the runway occupancy of a departure terminated on lift-off. The Working Group considered these improvements to be technically and operationally possible and believed they would come about as pressure increased. The Working Group urged the Working Party to incorporate more realistic figures in the model as soon as possible.

Overshoot ratio

10. The overshoot ratio is influenced by runway occupancy time and its relation to the approach interval. The model is programmed at present to indicate an overshoot when the time interval between arriving aircraft is low enough to produce an overlap of more than 10 seconds on the runway. The overshoot ratio in practice is very low (0·05 per cent over the 1969 summer period) and it was considered that a higher overshoot ratio ought to be acceptable in the future to permit the runway to be used more intensively. The overshoot ratio given by the model for segregated working is predictably high (2·3 per cent) and it was considered that this was not unacceptable as in practice the figure would probably be reduced by last minute tactical correction of the minimum intervals. The DORA representative wished it to be recorded that an acceptable mean or peak overshoot rate should be specified initially as the model was designed to calculate the approach separations at which controllers should aim to achieve a commensurate traffic flow.

Advent of elongated and jumbo jets and supersonic aircraft

11. It was assumed that elongated and jumbo jets would not constitute a separate ATC problem. In the absence of any definite information it was also assumed that the SST would be operable in the area with which the model was concerned as a subsonic aircraft and so would not present a separate problem.

Turbulent wake problem

12. At the time of the meetings there was no new information available on the effect of turbulent wake on separation requirements. It was assumed that, as in the past, the separation required for other reasons would exceed that required to obviate turbulent wake problems on the vast majority of occasions i.e. in all but still air conditions or when a very light wind was blowing directly down the runway.

APPENDIX 2 ANNEX C

Simulation runs and results

1. Figures 1, 2 and 3 show the present system reaction in terms of departure processing times and departure relays, all times being mean times for all aircraft simulated.

2. Following the runs which gave the above results the model was modified to include the system improvements forecast by the Working Party, (Appendix B) and the improvements in system capacity can be judged from figures 4(a) and (b) and 5(a) and (b) which show the mean of the peak 3 hours performance and 90 per cent and 10 per cent curves for the years 1974, 1976 and 1978. For comparison the mean results for the earlier years when the ATC system will approximate more closely to the present system are also shown. Figures 6, 7 and 8 show the effects of rescheduling on system reaction.

3. A more detailed picture of the system reaction for the 'most likely' mid-summer forecasts is shown in the following figures.

1974—Segregated—arrivals	Fig. 9a
1974—Segregated—departures	Fig. 9b
1974—Mixed —arrivals	Fig. 10a
1974—Mixed —departures	Fig. 10b
1976—Segregated—arrivals	Fig. 11a
1976—Segregated—departures	Fig. 11b
1976—Mixed —arrivals	Fig. 12a
1976—Mixed —departures	Fig. 12b
1978—Segregated—arrivals	Fig. 13a
1978—Segregated—departures	Fig. 13b
1978—Mixed —arrivals	Fig. 14a
1978—Mixed —departures	Fig. 14b

4. The upper traffic forecast has been tested against the most likely forecast and shown to correspond to a shift of about 2 years in the forecast.

Note: The figures referred to in this report are included at the back of Appendix 4.

APPENDIX 3

Hourly distributions of air transport movements by airway and aircraft type

These detailed estimates of the hourly pattern of arrivals and departures along airways are different in kind from the annual and representative daily traffic forecasts in Appendix 1. Whereas these latter bracket the expected outcome, the detailed estimates are intended to show a representative pattern of movements hour by hour rather than the expected outcome on any particular day. Clearly the chances of predicting the actual detailed pattern of hourly movements by airway and aircraft type are negligible, and any attempt to bracket the expected outcome in each detailed aspect would produce a forecast which was worthless as a representative pattern. But the erratic variations which occur in practice are important when considering the way in which traffic is handled by Air Traffic Control and in estimating the delays which may ensue. It was necessary therefore to use distributions with erratic and irregular features typical of what happens in practice, and to achieve this the distributions were based on what actually occurred in typical days in 1967, adjusted to take account of changes in the proportions of movements in each market, along each airway and in each aircraft type category.

The aircraft type categories were selected to distinguish variations in runway occupancy times and were:

(1) Supersonic transport aircraft and jet aircraft with a capacity of more than 300 seats.

(2) Other jet aircraft.

(3) Large turbo-prop aircraft (i.e. Britannia, Electra, Vanguard, IL 18 and TU 114).

(4) Small turbo-prop and piston-engined aircraft.

The proportions of air transport movements at Heathrow within each category were assessed for each year in each of the markets (i.e. Domestic, Irish Republic, Other Europe, North America and Other Long-Haul), based on the actual proportions in 1967 and 1968 and an assessment of future trends in airline re-equipment. As an example, by 1978, North America and Other Long-Haul movements are expected to be divided about equally between the first two aircraft categories whereas for traffic with Europe only one tenth of the movements are forecast in the first category with the remainder in the second category.

Turbo-prop and piston-engined aircraft are being phased out by the airlines using Heathrow. These forecasts assume that these aircraft will play no part in Heathrow's international traffic after 1976 excepting a small proportion of traffic with the Irish Republic. For both Domestic and Irish Republic traffic it has been assumed that by 1978 the bulk (84 per cent) of air transport movements will be in category 2 with 10 per cent in category 1 and only 4 per cent and 2 per cent respectively in categories 3 and 4.

Arrivals and departures in each hour of the day within each market assume the same diurnal distributions observed in the typical 1967 days, but adjusted to an equal number of arrivals and departures in each day as in tables 9 and 10 of Appendix 1. These hourly arrivals and departures were then apportioned into aircraft type categories. Small adjustments were made to the hourly movements at night to hold jet movements within the current summer restrictions and redistribute the overspill into the hours before and after the restricted period.

The movements in each aircraft category were further apportioned to the main airways into and out of Heathrow, in proportion to the observed distribution within each market. Arrivals were allocated between airways Green One West, Amber One North, Red One East, Blue 29 Inbound, Amber Two South and Red One South using the last airport of call. Departures were allocated between Green One West, Amber One North, Red One East, Green One East, Amber One South and Red One South according to the next flight destination.

APPENDIX 4

Report of the sub-committee on the ATC capacity of Heathrow using the DORA simulation model

1. Introduction

1.1 The Davies Working Party has amongst other things the task of predicting the period in which Heathrow will become saturated and to assist with this investigation, a general purpose runway capacity model developed by the Directorate of Operational Research and Analysis as a research tool has been adapted to assess the performance of the ATC system in the future.

1.2 A sub-committee of this Working Party has been formed to help present the results in a form suitable for the main committee.

1.3 The sub-committee comprised:

DORA —D. C. Soper—Chairman
Statistics Branch —B. Middleton
CP3 —R. Butler
Economic Services—N. Oulton
BAA —D. Miller
BEA —N. Søvig
BOAC —E. T. House
CTLA —A. Flowerdew } Observers
CTLA —J. Smith }

2. Simulation runs and basic assumptions

2.1 The model reproduces in considerable detail the control process which regulates the passage of aircraft to and from a runway and the spectrum of choices open to controllers operating the ATC system within the rules.

2.2 The model can be set to represent an airport operating in a given way and a single day's traffic can be simulated in about 30 minutes per run. At the end of each run the model prints out the life histories of all flights and certain essential statistics which describe the performance of the system in any desired detail.

2.3 The essential purpose of the present runs is to study the behaviour of the ATC system at Heathrow in the years in question (1972–1980) when the traffic is expected to be much greater than at present, and attempt to say when it is likely to reach its capacity limit.

2.4 The estimation of the ATC capacity of an airport involves:

(a) the preparation of traffic forecasts for these years;
(b) the inclusion of assumed ATC performance improvements in the model;
(c) the inclusion of proposed system changes in the model (if any).

2.5 The forecasting of future traffic demand has been carried out by another sub-group and forecasts supplied for the runs. The details of these are given in separate sub-committee working papers (WPTCs 26, 27, 32 and 45).

2.6 The forecasts in these working papers did not include the non-air-transport movements and these have since been added. The Working Party assumed that the July 1969 level of non-air-transport movements would be maintained but not exceeded on the argument that although the 'airline positioning' flights would increase, general aviation and other non-air-transport traffic would be dissuaded from using Heathrow in the busy periods.

2.7 The expected performance of the ATC system between 1974–1980 was discussed and decided by a Working Group of the DC(P) Working Party and the following changes were agreed:

(a) A reduction in the mean value of the inter-arrival time distribution from 110 seconds to 95 seconds.*

(b) A reduction in the mean of the 'runway occupancy time' distribution for arrivals from 55 seconds to 50 seconds with a corresponding change in the standard deviation to improve the upper performance values without materially changing the lower performance values.

(c) A change in the arrival separation for mixed working from 180 seconds to 170 seconds (assuming one departure between arrivals).

(d) A change in the outbound radar separation procedure to achieve a 3 ml separation on take-off. This has been translated into a mean separation of 75 seconds for aircraft following the same route. (A comparison with 3 minutes for fast after slow, 2 minutes for same type following same route and 1 minute all others shows no discernible difference in the results.)

(e) Coupled with (d) above is the further assumption that the distribution of the time a departure takes to leave the holding point and 'line-up' in a departure stream, will be the same as for 'lining up' before an arrival in a mixed stream. Also that clearance to 'take-off' will not depend upon the previous departure turning off the extended centre line but on 'airborne', subject to the minimum clearance being achieved.

(f) Outbound delays due to the absence of flight level clearance should not occur in the period in question.

2.8 The model was first run as a simulation of the existing system to provide a comparison with known results for the purpose of validation.

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*This change does not take into account the introduction of Computer Assisted Approach Sequencing which could be in operation by 1973/74.

Subsequently the model was run with the assumed performance changes, listed in para. 2.7, to simulate future performance (1974–80) of the system. The results are described in more detail in Section 4.

2.9 The sub-committee decided that the model should be run to simulate a typical mid-summer day in the years 1974, 1976 and 1978 when saturation seemed most probable. It also considered the ways in which air operators would suffer if the demand were allowed to rise to the levels predicted in these years.

2.10 Although there are many ways in which a flight may suffer if the demand on the common facilities is too high, the most significant overall effect is considered to be the delay suffered at various points in the system and this is regarded as the main measure of congestion. The ATC delays (or perhaps more exactly the queueing delays) are the times spent by an aircraft in excess of the time which would be required in the absence of other aircraft in the system. The average hourly delay is an indicator of the relative position between years but the spread of delays is of major importance from the airlines' point of view.

2.11 In the presentation of the simulation results the sub-group decided that the most meaningful way to present the results would be to show on a single graph the relation between demand, movement rates and the distribution of delays suffered throughout the 24 hours of a summer day in the years in question.

2.12 The results achieved for the delay also show the extent of the variation and this is obtained by running the simulation ten times and showing the spread of results in any one hour by plotting the 90 and 10 percentile delay levels. This means there is a probability that one in ten aircraft will have delays greater than the 90 per cent line and one in ten will have delays less than the 10 per cent line. (See Figures 4 and 5.)

3. Assessment of capacity

3.1 Inherent in any ATC system is a *service rate* (or runway acceptance rate) which is the mean rate of arrival or departure of traffic when the demand is such that a queue of one or more aircraft persists. Thus the service rate of any ATC system is the average of the movement rates achieved when the demand is increased beyond this point. At this level of demand the queues build up and excessive delays will occur.

3.2 Some delay, however, is inevitable if the runways are to be used efficiently. The question is at what level does delay become economically intolerable.

3.3 The first step necessary in answering the question is to find out the relationship between delay and demand for each type of traffic (arrivals and departures) and for each of the possible modes of operation.

3.4 The delays which result depend not only on the overall level of demand in relation to the service rate but to the following characteristics of the demand:

- (i) Traffic distribution between airways.
- (ii) Mix of aircraft types.
- (iii) Diurnal pattern of arrival/departure ratio.
- (iv) Diurnal pattern of North/South demand ratio.
- (v) Variation in hourly level of demand due to deviation from schedule.
- (vi) Scheduled traffic distribution within each hour.
- (vii) Pattern of inter-arrival intervals.
- (viii) Demand level in previous hour (gradient of hourly demand curve).

3.5 The assessment of the capacity of a runway system in terms of delay involves the operation of the model in its appropriate form and the generation of delay patterns throughout the 24 hours when the system is subjected to the demand patterns forecast for any one year. Each run is then repeated ten times to give some idea of the probable spread of results and presented to show this.

3.6 In para. 5 a method of assessing saturation is proposed based on the re-scheduling of traffic—provided that a tolerable level and spread of delay can be accepted as a criterion for determining saturation.

4. Explanation of results

4.1 In the first instance it has been necessary to establish the relation between present day performance and the results from the model. A series of validation runs were produced initially and accepted at a meeting of DC(P)'s Working Party dealing with the ATC aspects of the problem.

4.2 The general relationship between the model results and present performance is shown by including 1968 plots on Figures 1, 2 and 3 which show the delay/demand relationship with the 'most likely' traffic forecasts up to 1975.

4.3 The ATC system was then modified to include all those improvements considered probable by DC(P)'s staff as enumerated in para. 2.7, and the improvement achieved can be judged from Figures 4a, 4b, 5a and 5b which show the mean of the peak 3 hours performance and 90 per cent and 10 per cent curves for the years 1974, 1976 and 1978, and for comparison the mean results for the earlier years when the ATC system will approximate more closely to the present system. The appreciable jump in improved performance with regard to mean delay at the year 1974 is due to the inclusion of all the ATC system improvements from that year. In reality a gradual or phased implementation will occur from 1974 but no indication of the timing and extent of this process is possible at this stage. All that can be said is that at least in the earlier part of the period in question the mean delays may occur between the 'existing system curve' and the 'improved system curve'.

4.4 The reductions in delay shown in Figures 4 and 5 are due to the performance improvements given in para. 2.7.

4.5 The hourly pattern of delays for the most likely mid-summer forecasts are shown in the following figures:

1974	Segregated	arrivals	Figure 9a
1974	Segregated	departures	Figure 9b
1974	Mixed	arrivals	Figure 10a
1974	Mixed	departures	Figure 10b
1976	Segregated	arrivals	Figure 11a
1976	Segregated	departures	Figure 11b
1976	Mixed	arrivals	Figure 12a
1976	Mixed	departures	Figure 12b
1978	Segregated	arrivals	Figure 13a
1978	Segregated	departures	Figure 13b
1978	Mixed	arrivals	Figure 14a
1978	Mixed	departures	Figure 14b

4.6 The upper traffic forecast has been tested against the most likely forecast and shown to correspond to a shift of about 2 years in the forecast.

4.7 The mean service rates for the existing and future ATC systems are:

Segregated Mode	*Existing*	*Future*
Arrivals	32 movements/hr	38 movements/hr
Departures	40 movements/hr	46 movements/hr
	—	—
Total	72	84

4.8 In the mixed case the service rate has less meaning as the departure rate is limited by the arrival demand and not factors inherent in the ATC system. Using the values set in para. 2.7 the limiting capacity of each runway varies between 38 movements when they are all arrivals and 46 movements when they are all departures with a value of about 42 when the ratio of arrivals to departures is 1 : 1. In the traffic samples the ratio varies between limits of 0·6 and 1·6. At the lower levels of demand the movement rate is limited by the random nature of the demand.

4.9 A summary of the mean delays in the peak 3 hours and the daily mean delay is shown in the following table.

Table 1
Future ATC Mean delays*

	Delay—mins. (mean of 10 runs)							
	Segregated				Mixed			
Year	Arrivals		Departures		Arrivals		Departures	
	Peak (3 hrs)	Mean (24 hrs)	Peak (3 hrs)	Mean (24 hrs)	Peak (3 hrs)	Mean (24 hrs)	Peak (3 hrs)	Mean (24 hrs)
1974	5·7	2·86	4·71	2·14	4·42	2·74	9·25	4·99
1976	8·8	3·66	6·94	2·86	6·66	3·67	13·26	6·36
1978	16·6	6·03	10·00	3·89	11·78	5·24	23·05	10·08

**Note.* The mean delay figures in the table have been estimated on the basis that *all* the assumed improvements in performance, given in para. 2.7, have been implemented for the years 1974/76/78. (See also para. 4.3.)

4.10 It follows from the very dissimilar service rates under segregated working that the arrival delays will on average be much higher than the departure delays and this can be seen by comparing values in Table 1 above. Under mixed working the situation is reversed and departure delays exceed the arrival delays. This is due in part to the fact that the runways function independently on departures and a north/south imbalance in the demand may create large delays on one runway whilst the other is lightly loaded.

4.11 The overshoot rates experienced were 2·2 per cent for segregated working and 0·7 per cent for mixed working. The overshoot ratio under segregated working in practice is 0·05 per cent and the large difference arises predominantly from the assumption in para. 2.7(a) that the separation of arrivals on approach can be reduced from 110 seconds to 95 seconds without a corresponding reduction in the variation of performance around these values prior to the introduction of CAAS.

4.12 In practice the overshoot ratio is probably much less than the theoretical value because of a liberal interpretation of the regulations which say that clearance can be given to land if the preceding aircraft can 'reasonably' be expected to be more than 2500 metres along the runway when the next aircraft crosses the threshold. To allow for this the model does not regard the runway as being occupied if the leading aircraft is within 10 seconds of leaving the runway when the following aircraft crosses the threshold.

5. Effect of scheduling

5.1 The present and past levels of traffic at Heathrow are the result of scheduling to keep the planned level of demand within the capacity of the airport. Thus past trends are a reflection of the natural growth of demand within the various markets only insofar as the scheduling committee has been able to accommodate the annual growth within the planning ceilings for each year. Table 2 shows the degree to which changes were necessary in past years.

5.2 The planning levels which will be agreed in future years are unknown and the degree to which the 'free' demand will be adjusted to keep within future planning ceilings is also unknown. It is possible however to suggest rules which should be observed by future scheduling committees if they wish to avoid the excessive mean delays which can occur.

5.3 The suggested planning criteria for keeping delays as low as possible are:

(a) The scheduled demand levels of traffic per hour should not exceed N per cent of the mean service rate (where N is the level at which an acceptably low and stable level of delay results).

(b) The number of hours for which this level of demand can persist should be specified.

(c) The present practice of allowing 2 or 3 hourly peaks in excess of the sustainable level when scheduling should be discontinued. The variations about the planned levels which occur in practice are large enough in themselves.

(d) The planned disposition of aircraft within the hour should be such as to constrain the number scheduled in any unit of time to near the mean level.

(e) The northerly and southerly traffic should be scheduled separately if mixed working is envisaged.

5.4 *As an example* of the value of scheduling we have taken the 1978 arrivals forecast and subjected it to schedule limitations by limiting the demand in any one hour to:

(a) 100 per cent of the mean service rate.

(b) 90 per cent of the mean service rate.

The surplus movements are accommodated in the adjacent hours. For instance, in the example taken it proved necessary to move 22 movements from the morning peak (15 forward and 7 backwards) into the adjacent hours whilst in the afternoon 4 movements had to be moved (one forward and 3 backwards). A total of 26 movements.

5.5 Before doing this it was necessary to idealise the daily shape to remove the hourly fluctuations partly because these confuse the experiment but mainly because the model applies practical hourly variations anyway.

5.6 *As an example*, the results for arrivals in the year 1978 are shown in terms of:

(a) Idealised (Figure 6).

(b) 100 per cent service rate (Figure 7).

(c) 90 per cent service rate (Figure 8).

5.7 These show that if the scheduled demand is limited to 90 per cent of the service rate a mean delay of about 5 minutes for 6 hours is achieved whilst for higher demands it rises. Comparable results can be achieved for departures. Thus it appears in this example that if the demand is limited to about 90 per cent of the service rate this rate can be sustained for a long period (6 hours) during the day without an appreciable rise in the mean delay. The precise level at which to limit the demand under working conditions can be determined if the technique is accepted. In practice it will of course vary about this level and the 100 per cent of service rate level will be reached for short periods but in general the delays will not rise as significantly as they do with an uninhibited demand.

5.8 The acceptability of this proposal is being assessed by the airline members of the sub-committee and a separate report on this will be made to the main committee.

5.9 Subsequent results given in Figures 15A and 15B show how the overall hourly mean delays for arrivals and departures vary when the demand is fixed at levels between 85 per cent and 95 per cent of the service rate. The figures for this curve were obtained by running the model with a fixed demand (85 per cent, 90 per cent or 95 per cent) for a 24 hour period and repeating it five times. The limits within which 95 per cent of the distribution of the individual hourly mean delays obtained from the simulation runs can be expected to lie are also shown.

5.10 The precision of the estimate of the overall hourly mean delay per aircraft can be indicated by a confidence interval. For example, when the demand is fixed at 90 per cent of the service rate the overall hourly mean delay for arrivals is estimated to be 4·8 minutes as in Figure 15A, and one can be 95 per cent confident that any other estimate of the overall hourly mean delay will lie between 4·2 minutes and 5·4 minutes. (See Annex A.)

6. Summary and recommendations

6.1 The capacity of an ATC system subjected to a free demand pattern is difficult to assess without a clear definition of 'tolerable delay', which has proved difficult to obtain. The cost and inconvenience of delay varies with the route length and other operational factors and therefore is probably different (perhaps widely different) for the various airline operators. For this reason it has proved necessary to consider alternative ways of assessing capacity.

6.2 The hourly rate of processing arrivals or departures by the ATC system is known as the movement rate. An upper limiting spread of values of this will occur during the busiest days in summer when queues persist in the TMA and this is called the service rate (or runway acceptance rate). The spread is due to random influences and the average of these values is called the mean service rate to differentiate between a particular result and the general position. Queues and the associated delays can rise steeply if the demand rate on the system is maintained at or above this value of the service rate.

6.3 Thus in the planning (or scheduling) of demand it is important to see that the probability of this value being reached or exceeded is kept low.

6.4 The adaptation of the daily demand pattern to fit the propensities of the system faces the realities of the situation and the setting of a limit to the planned level of demand is inevitable.

6.5 It is suggested that a planning level of *about* 90 *per cent* of the service rate would ensure the absence of a prolonged build up in the level of delay.

6.6 The ATC system as modified for the late 1970s gives mean service rates as follows:

Arrivals	38 movements
Departures	46 movements
	—
Total	84 movements

6.7 If a limit of about 90 per cent of service rate is accepted the sustainable movement rates become:

Arrivals	34 movements
Departures	42 movements
	—
Total	76 movements

6.8 The total movement figures apply also to the mixed mode using the values given in para. 2.7 but its sensitivity to variation in the arrival/departure and north/south movement ratios in the demand means that this mode is better able to adjust to arrival/departure imbalances, but less able to adjust to north/south departure imbalances. The best mode of operation depends therefore upon the nature of the expected demand.

6.9 The hourly performance of the ATC system in both its modes for the most likely estimate of demand in the years 1974–1978 is shown in Figures 9–14 and the average hourly delays which would be experienced if no re-scheduling were done, are shown. The annual position is shown in Figures 4 and 5.

6.10 The effect of re-scheduling in terms of the number of flights which must be moved to obtain a planning limit of 90 per cent of service rate (for example) can be seen by placing a ruler across the demand curve at the appropriate level and counting the movements in excess of this. The airlines can then judge the point in time when the number and extent of re-scheduling required would probably be unacceptable to them.

D. C. SOPER
Chairman of Sub-Committee

April 1970

Table 2

Summary of changes to operators Schedules at London, Summers 1965/6/7/8

Limitations

Aircraft Movements	*Summer 1965*	*Summer 1966*	*Summer 1967*	*Summer 1968*
Dep. & Arr. combined				
Limit imposed	—	—	58 per 3 hrs 50 per hour sustained	62 per 2 hrs 54 per hour sustained
No. of services changed	—	—	7	—
Average change	—	—	0:55	—
Longest change	—	—	1:00	—
Departures				
1. *5 min. departure rate*				
Limit imposed	4	4	5	5
No. of services changed	54	15	67	22
Average change	0:09	0:06	0:08	0:10
Longest change	0:20	0:20	1:30	0:50
2. *10 min. departure rate*				
Limit imposed	8	8	8	8
No. of services changed	—	—	—	—
Average change	—	—	—	—
Longest change	—	—	—	—
3. *Hourly departure rate*				
Limit imposed	34	34	36	36
No. of services changed	8	2	21	4
Average change	0:05	0:45	0:16	0:09
Longest change	0:05	0:45	0:25	0:10
Arrivals				
1. *5 min. arrival rate*				
Limit imposed	4	4	5	5
No. of services changed	3	15	18	13
Average change	0:05	0:23	0:05	0:06
Longest change	0:05	0:45	0:05	0:15
2. *10 min. arrival rate*				
Limit imposed	8	8	8	8
No. of services changed	—	—	—	2
Average change	—	—	—	0:05
Longest change	—	—	—	0:05
3. *Hourly arrival rate*				
Limit imposed	24	24	30	34
No. of services changed	25	35	8	1
Average change	0:22	0:27	0:19	1:00
Longest change	0:35	1:10	0:50	1:01

Confidence interval as a precision measure for the estimate of the mean

1. The calculation of an average or mean value from a statistical sample of observations or measurements is an estimate of the ideal or 'true' value of the population mean, which in general remains unknown. A measure of the precision of estimated value of the mean can be obtained using a confidence interval. In statistical calculations 90, 95 or 99 per cent confidence intervals are most commonly used in this connection. Generally, the greater a sample size is used in estimating the average or mean the more confident we are in approximating to the 'true' mean value.

2. Essentially, a 95 per cent confidence interval for the true mean of a population of observations would involve the following interpretation: if in a series of very many repeated sampling experiments an interval for the range of mean estimates were calculated, we would in the long run be correct 95 per cent of the time in claiming that the true mean value is located within the calculated sample interval—and we would be wrong 5 per cent of the time. The extreme values of the calculated interval are called the confidence limits of the mean. Any requirement for increasing the level of confidence, for a given sample size, leads to an increased interval length.

3. The above strictly technical interpretation may be somewhat difficult for a non-statistician to grasp. Therefore a less technical statement is usually, even if more loosely, made. We can consider a 95 per cent confidence interval as a range of values within which we are 95 per cent sure (i.e. highly confident) that the true value of the mean is contained.

FIG.1

RUNWAY SIMULATION MODEL
EXISTING ATC SYSTEM–INITIAL RUNS

SEGREGATED MODE
DEPARTURE
PROCESSING TIME

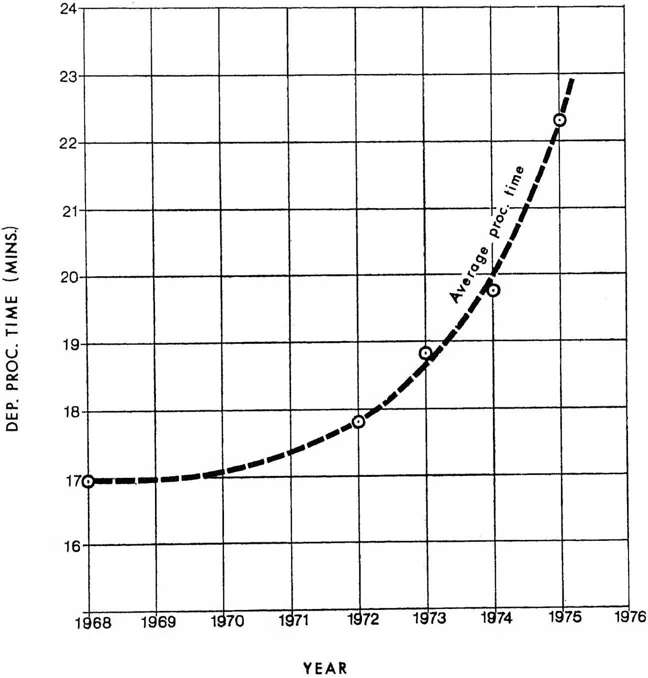


FIG. 2

RUNWAY SIMULATION MODEL
EXISTING ATC SYSTEM-INITIAL RUNS

SEGREGATED MODE

ARRIVAL PROCESSING TIME

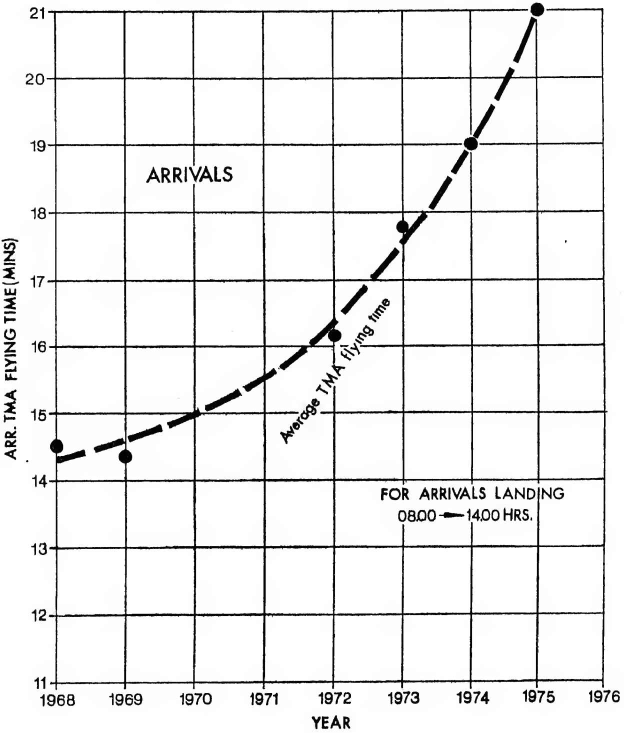


FIG. 3

RUNWAY SIMULATION MODEL
EXISTING ATC SYSTEM–INITIAL RUNS

SEGREGATED MODE
DEPARTURE DELAYS

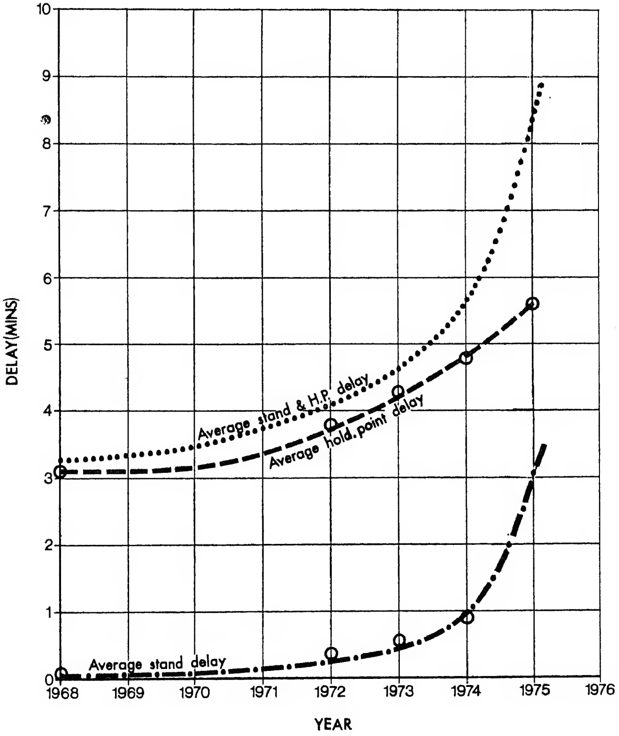


Fig. 4a

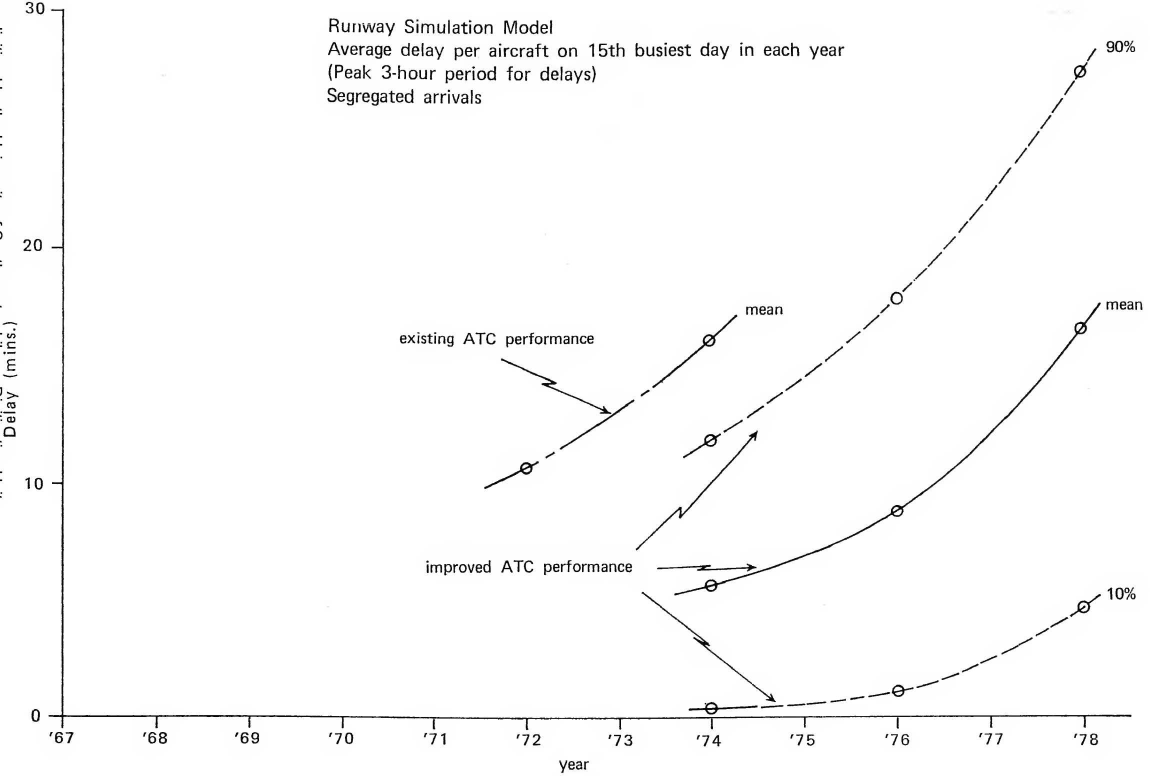

Runway Simulation Model
Average delay per aircraft on 15th busiest day in each year
(Peak 3-hour period for delays)
Segregated arrivals
Delay (mins.)
30
20
10
0
'67
'68
'69
'70
'71
'72
'73
'74
'75
'76
'77
'78
year
existing ATC performance
mean
improved ATC performance
90%
mean
10%

Fig. 4b

Runway Simulation Model
Average delay per aircraft on 15th busiest day in each year
(Peak 3-hour period for delays)
Segregated departures

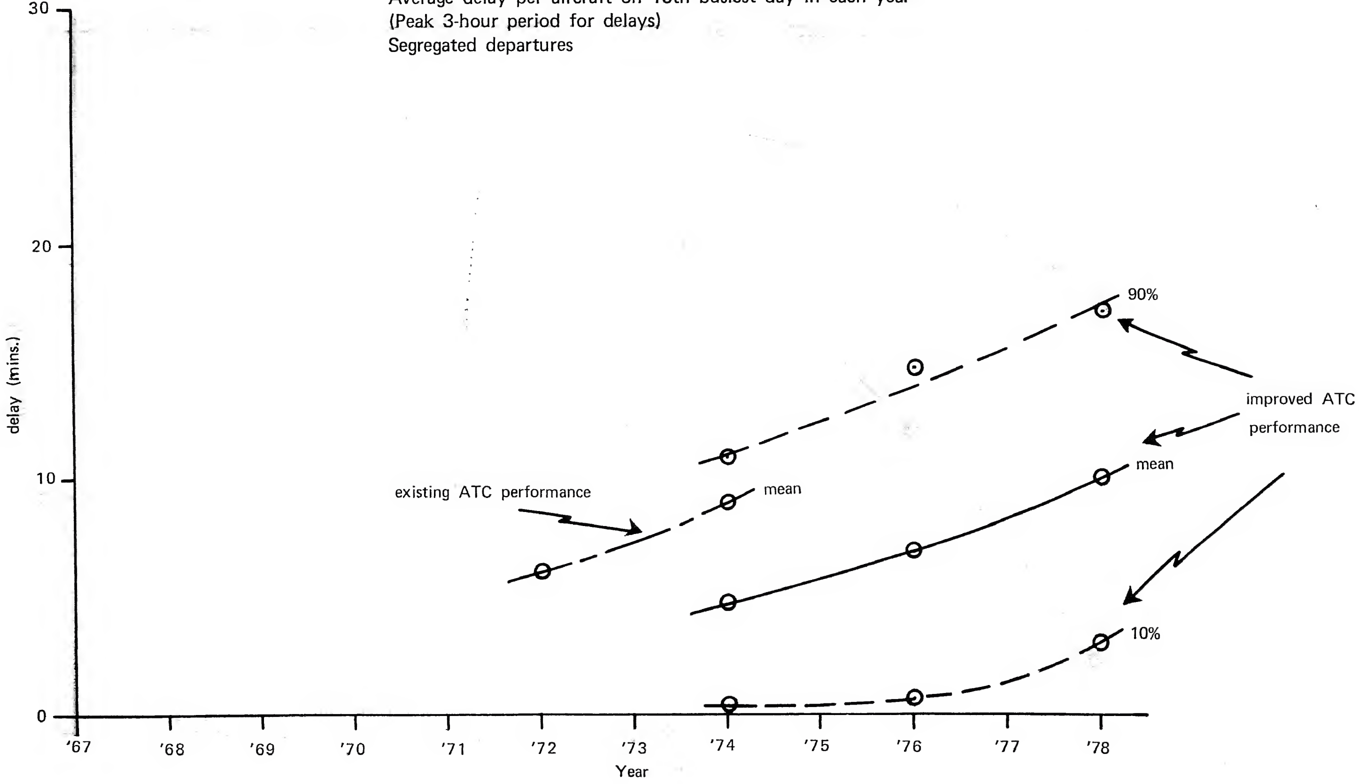
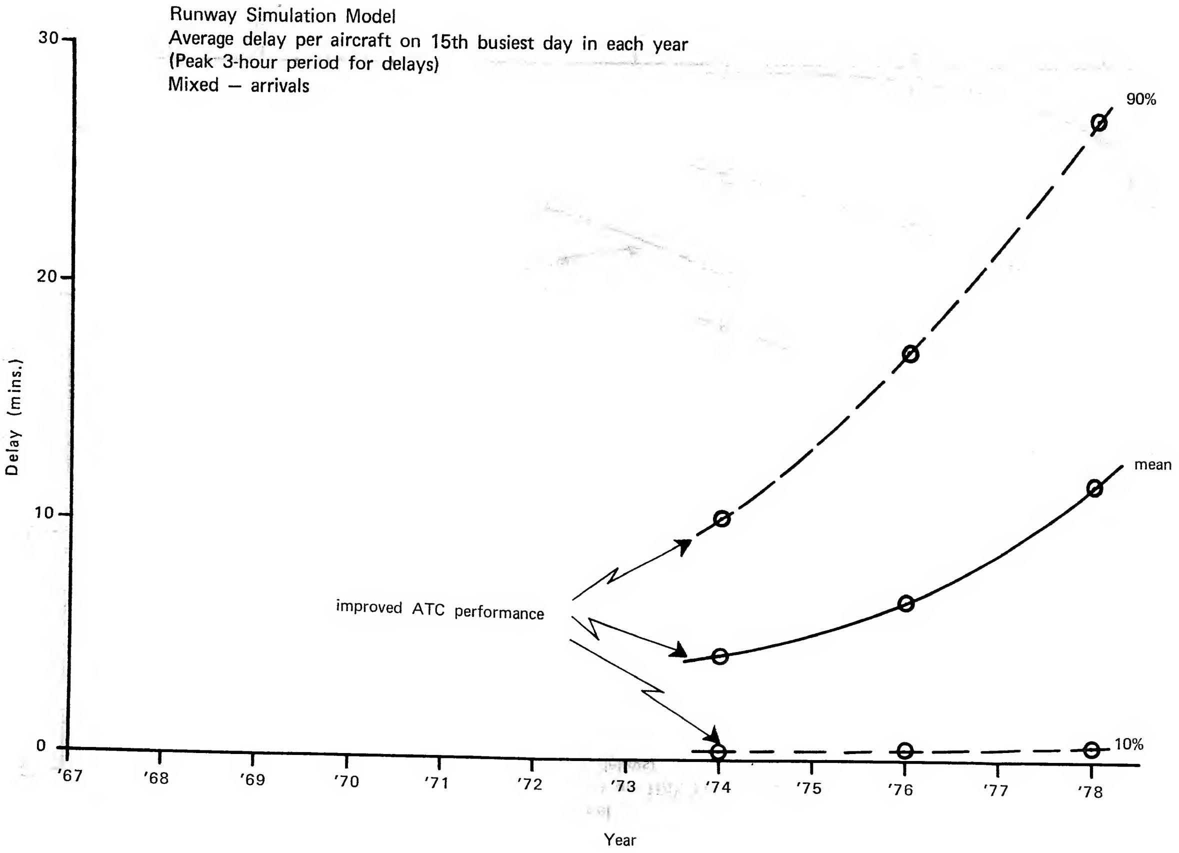
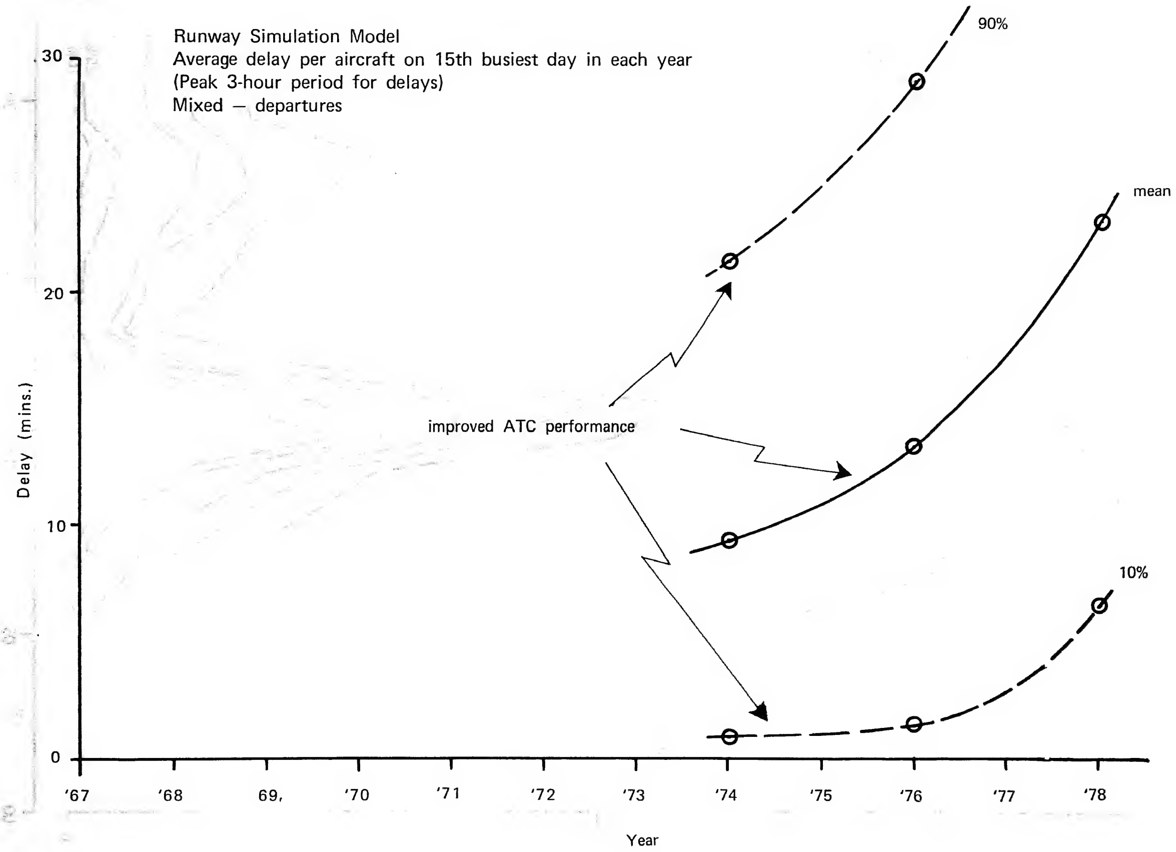


Fig. 5a



Runway Simulation Model
Average delay per aircraft on 15th busiest day in each year
(Peak 3-hour period for delays)
Mixed – arrivals

Fig. 5b



Runway Simulation Model
Average delay per aircraft on 15th busiest day in each year
(Peak 3-hour period for delays)
Mixed — departures

Fig.

Runway Simulation Model (improved ATC performance)
1978 — idealised forecast
Segregated arrivals

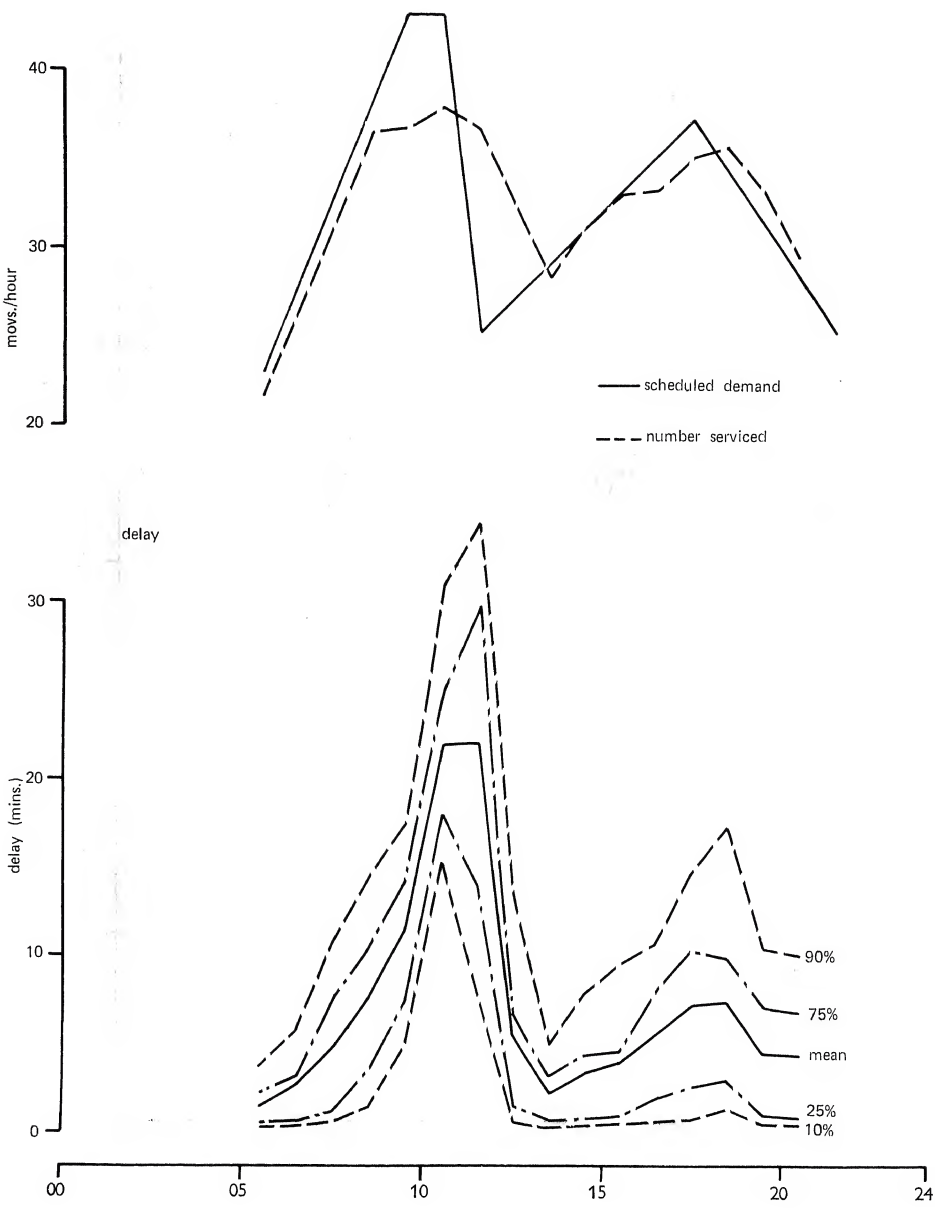


Fig. 7

Runway Simulation Model (improved ATC performance)
1978 – rescheduled forecast – peak limited to service rate
Segregated arrivals

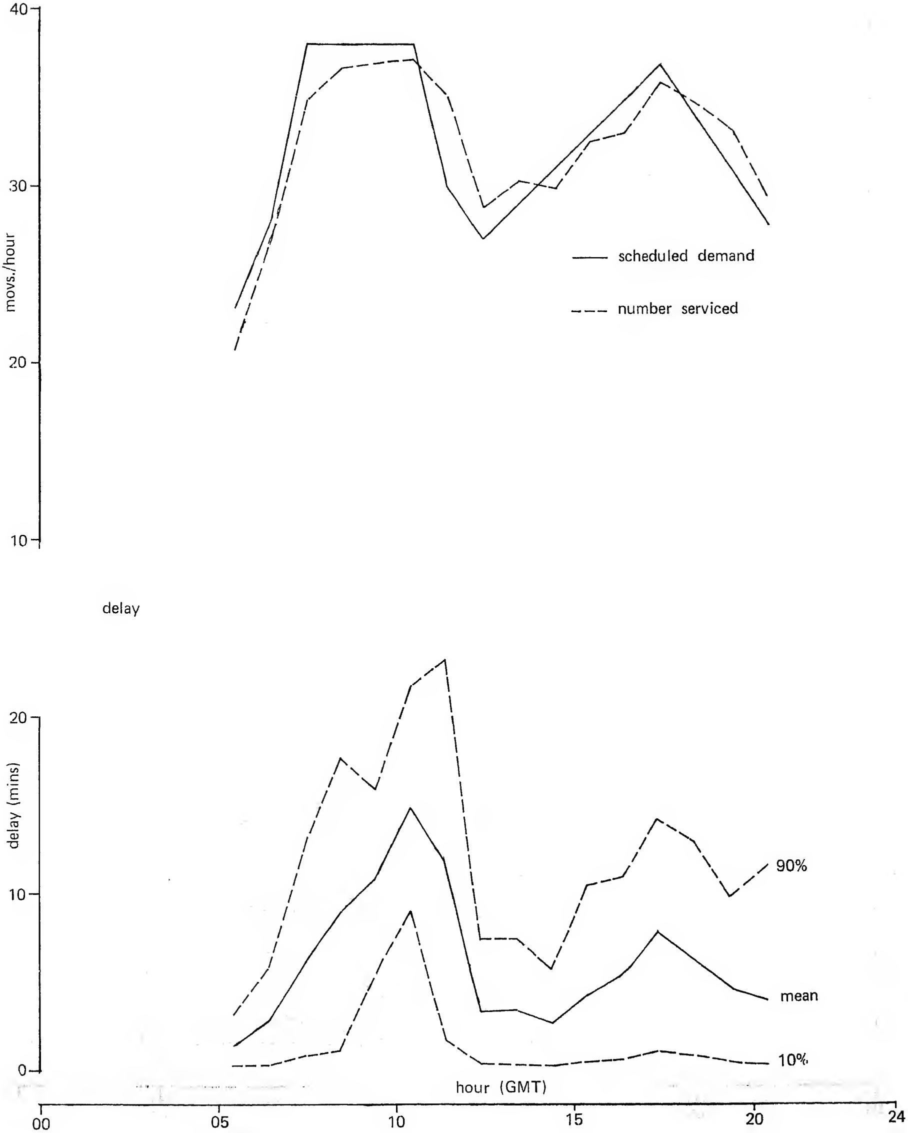


Fig. 8

Runway Simulation Model (improved ATC performance)
1978 – rescheduled forecast – peak limited to 90% of service rate
Segregated arrivals

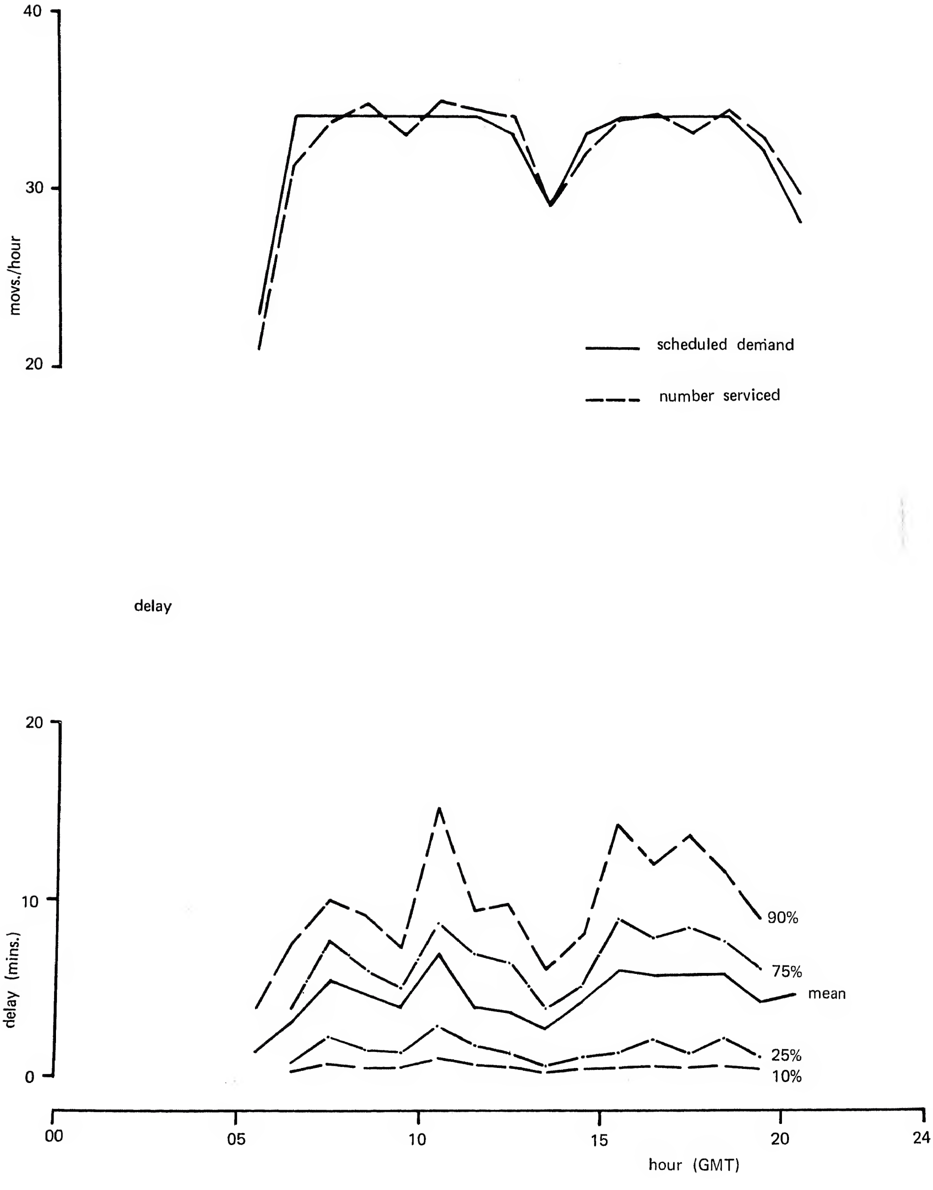
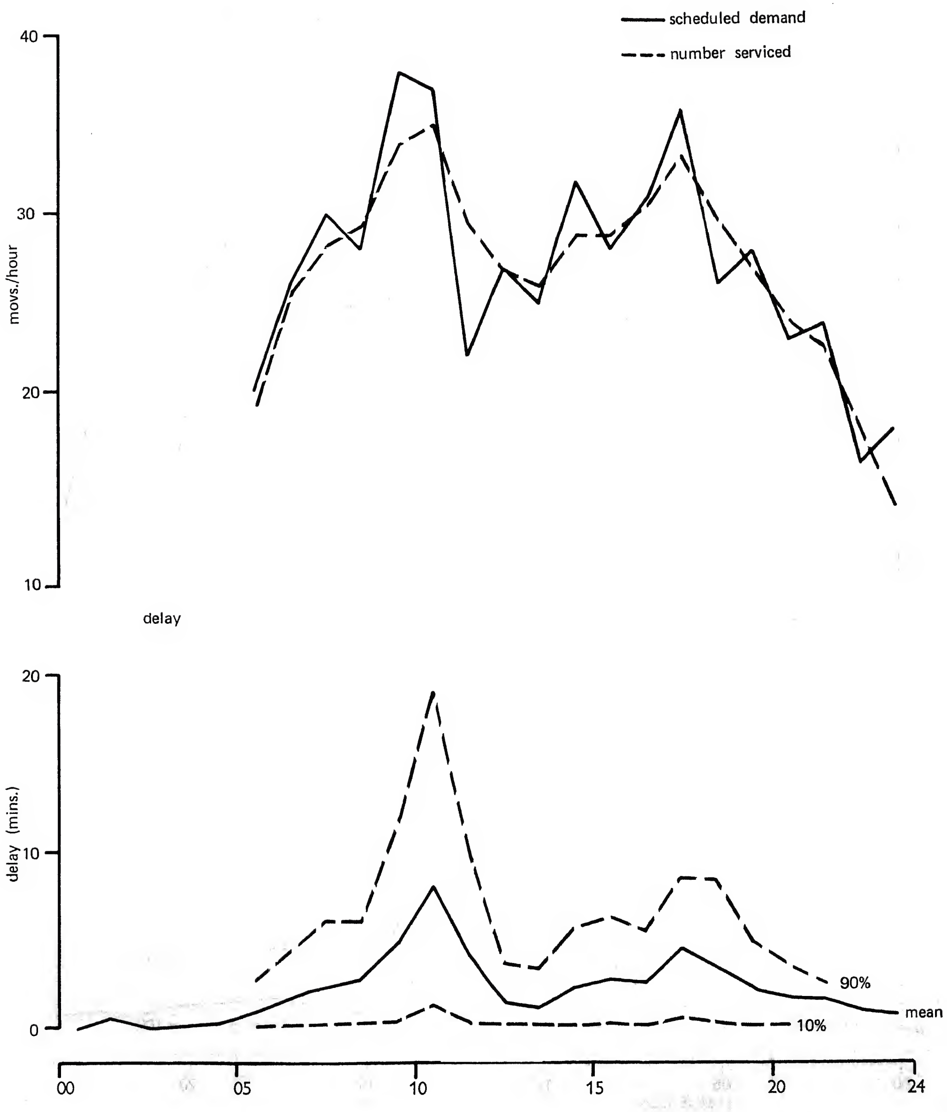


Fig. 9a

Runway Simulation Model (improved ATC performance)
1974 – scheduled forecast (incl. G.A. etc.)
Segregated arrivals



Runway Simulation Model (improved ATC performance)
1974 — scheduled forecast (incl. G.A. etc.)
Segregated departures

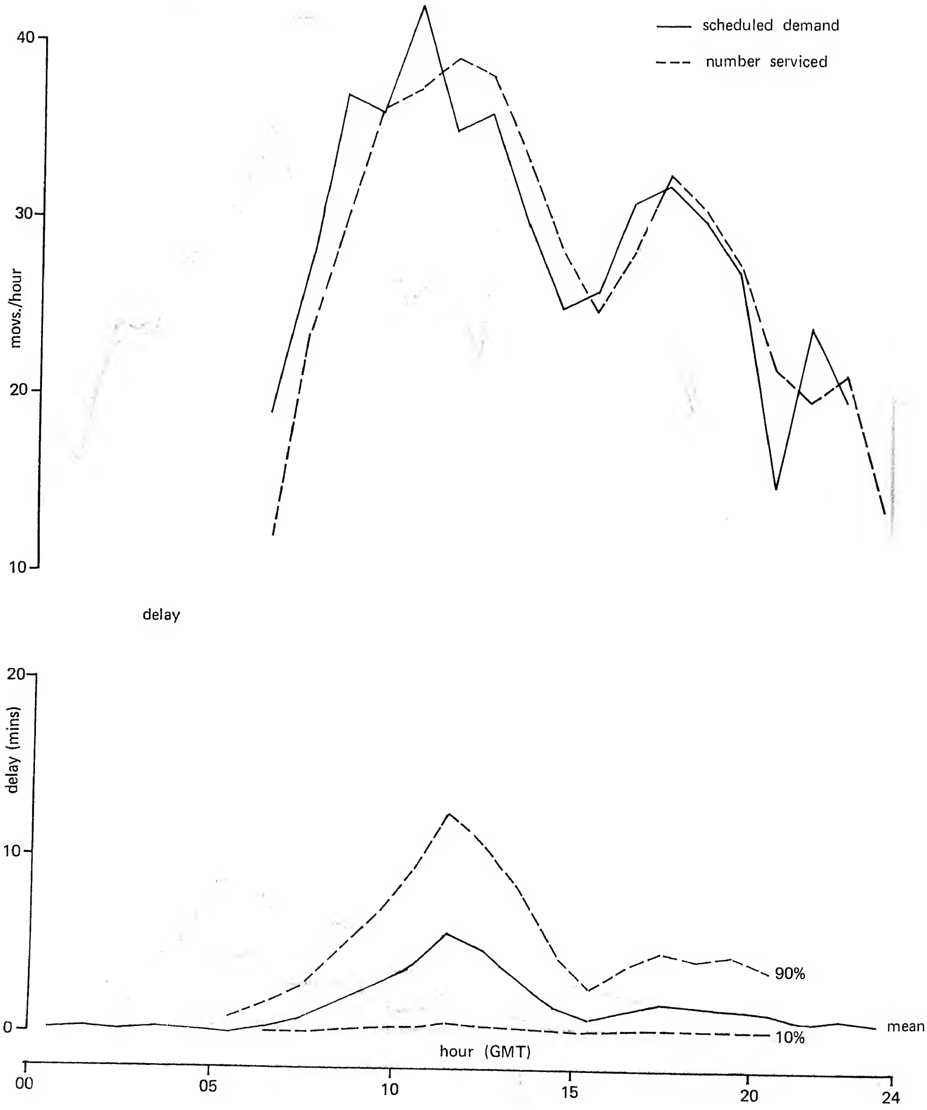
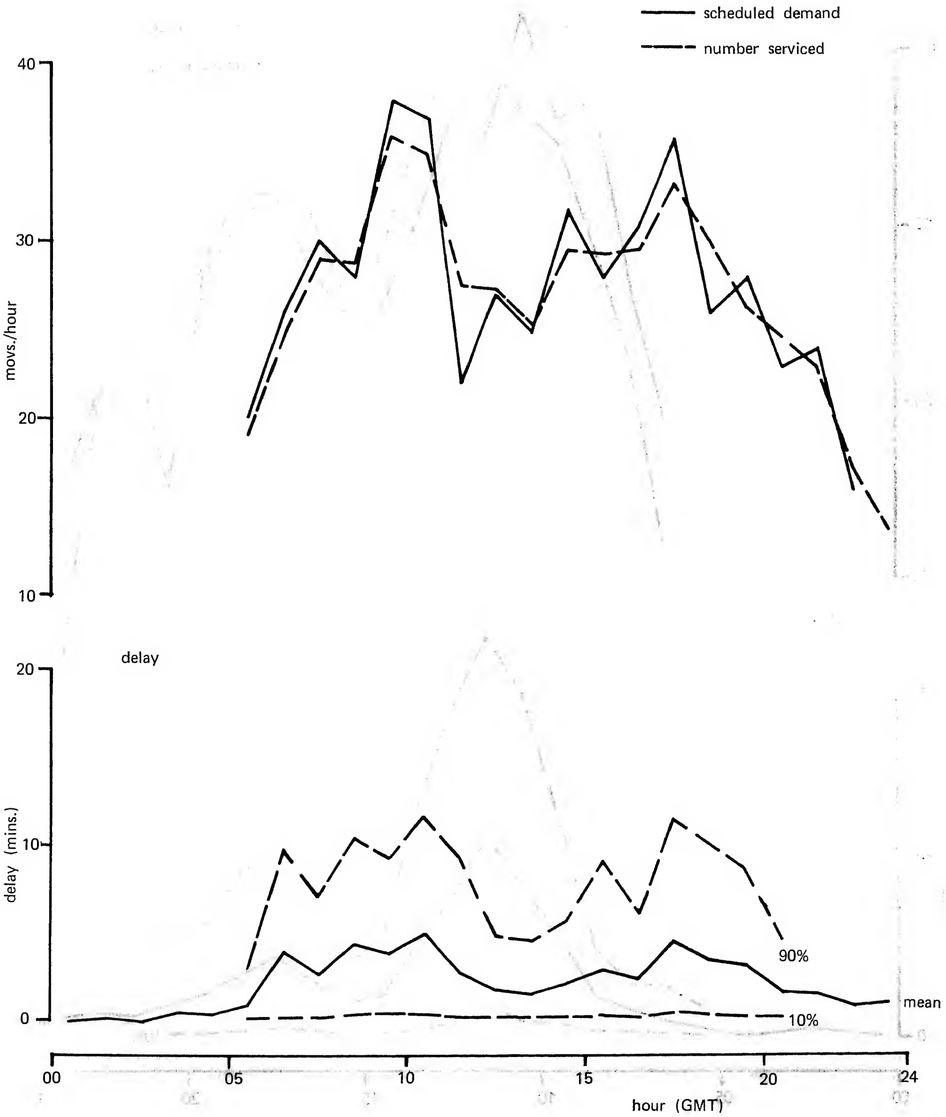


Fig. 10a

Runway Simulation Model (improved ATC performance)
1974 – scheduled forecast (incl. G.A. etc.)
Mixed – arrivals



Runway Simulation Model (improved ATC performance)
1974 – scheduled forecast (incl. G.A. etc.)
Mixed – departures

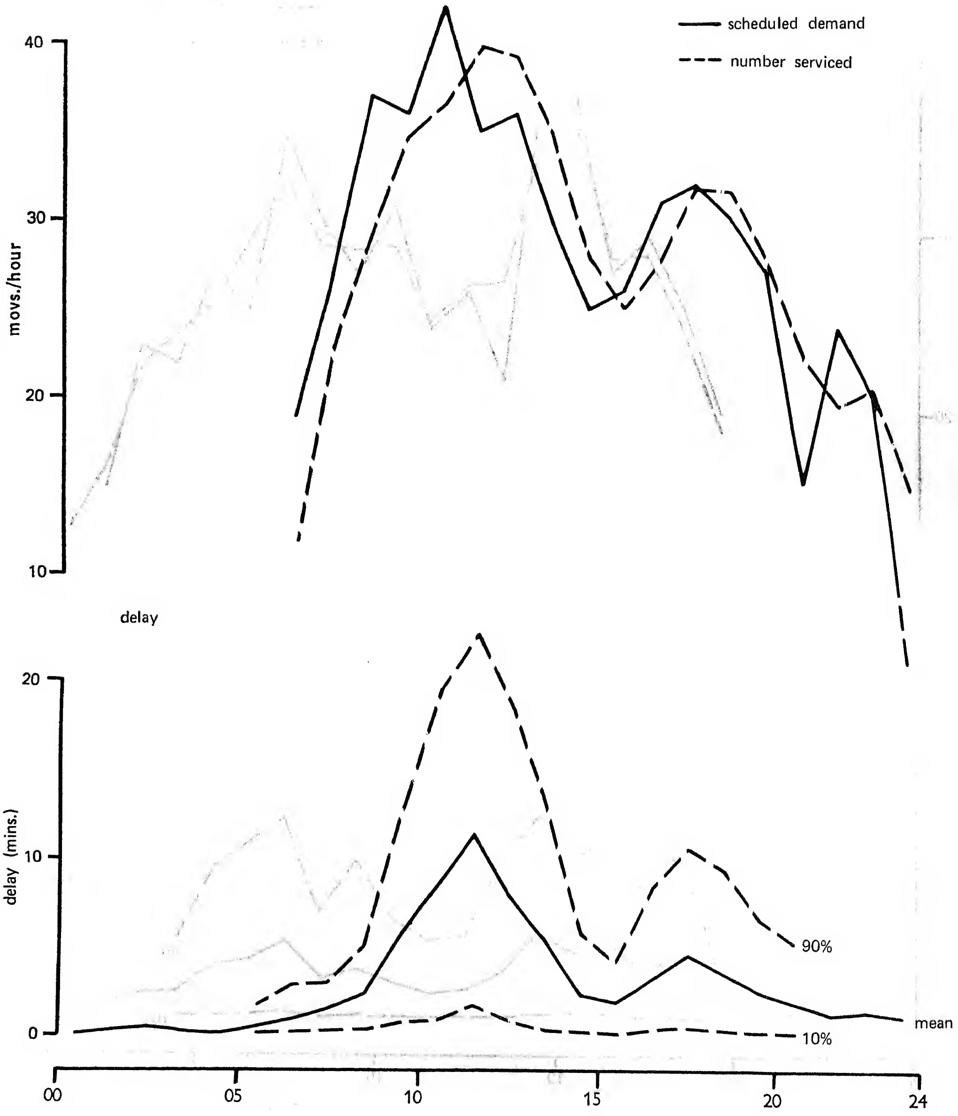
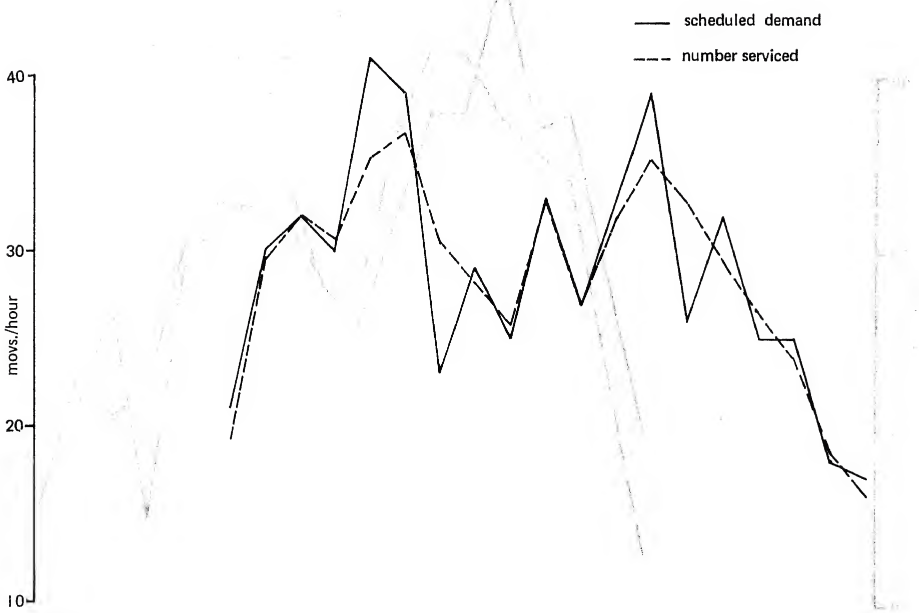


Fig. 11a

Runway Simulation Model (improved ATC performance)
1976 – scheduled forecast (incl. G.A. etc.)
Segregated arrivals



delay

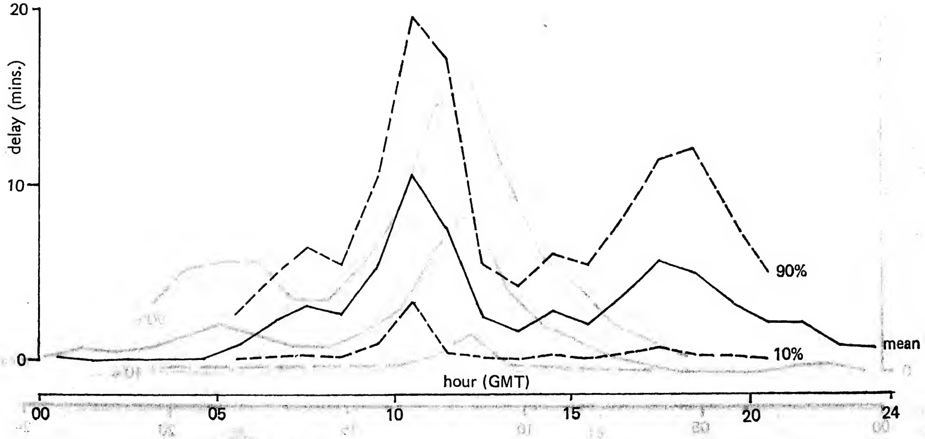


Fig. 11b

Runway Simulation Model (improved ATC performance)
1976 – scheduled forecast (incl. G.A. etc.)
Segregated departures

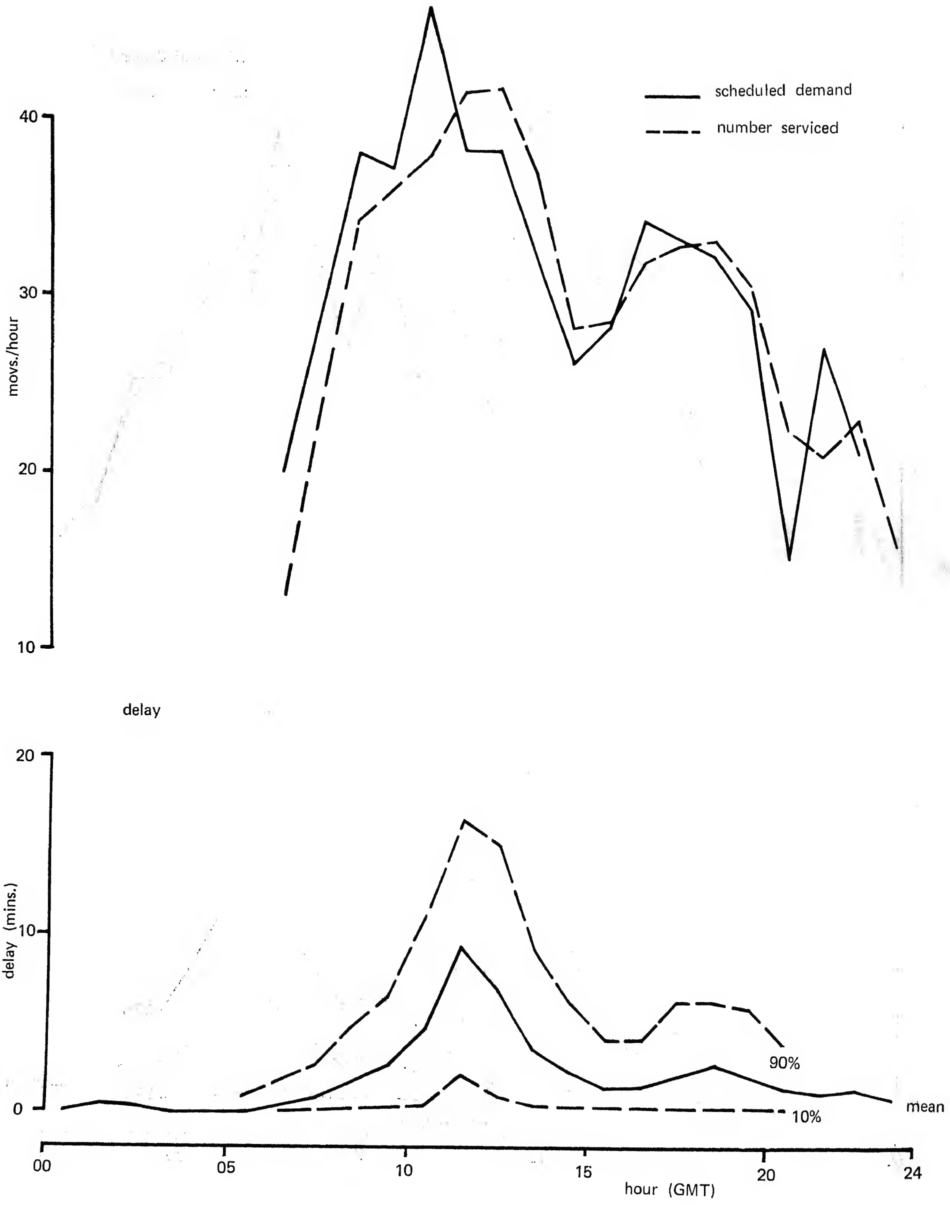


Fig. 12a

Runway Simulation Model (improved ATC performance)
1976 – scheduled forecast (incl. G.A. etc.)
Mixed – arrivals

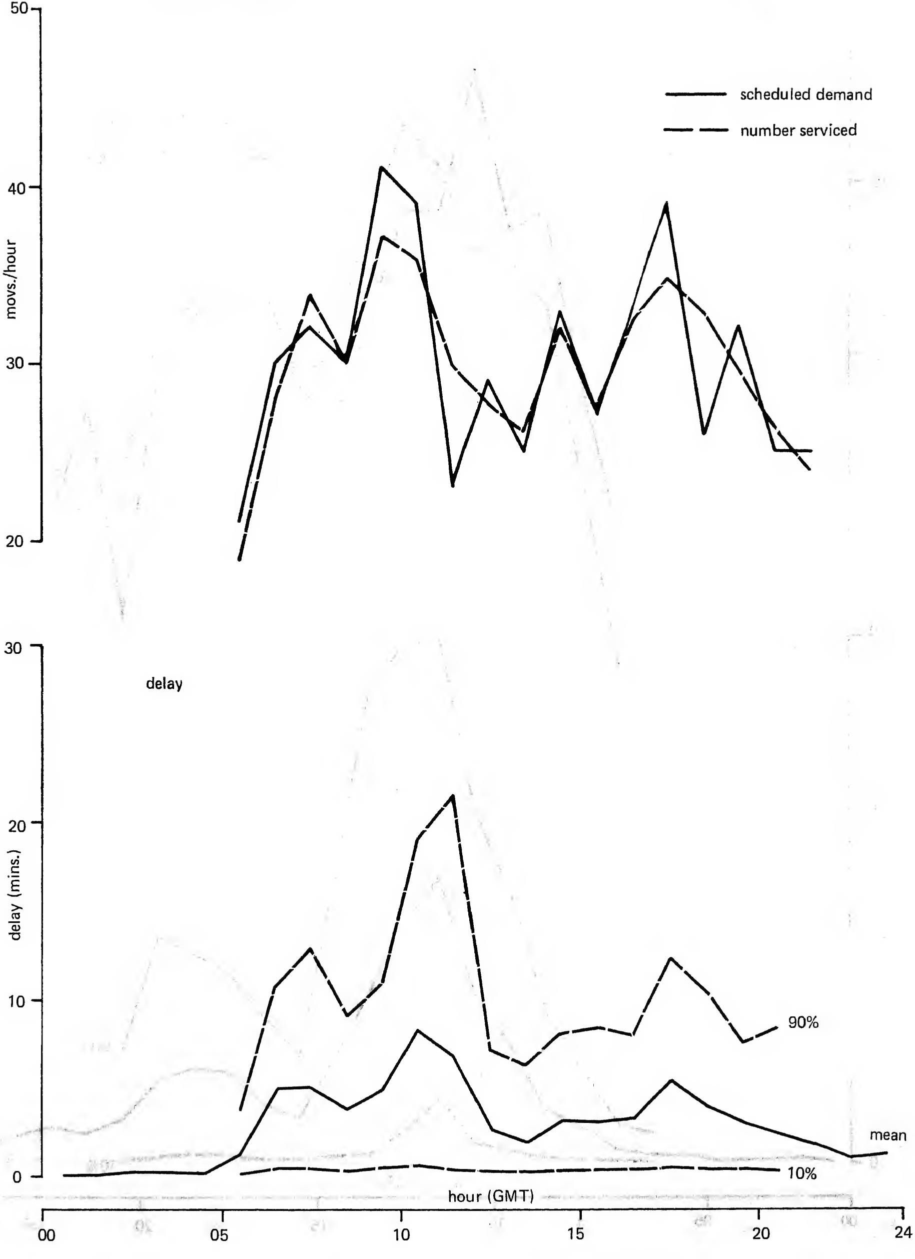
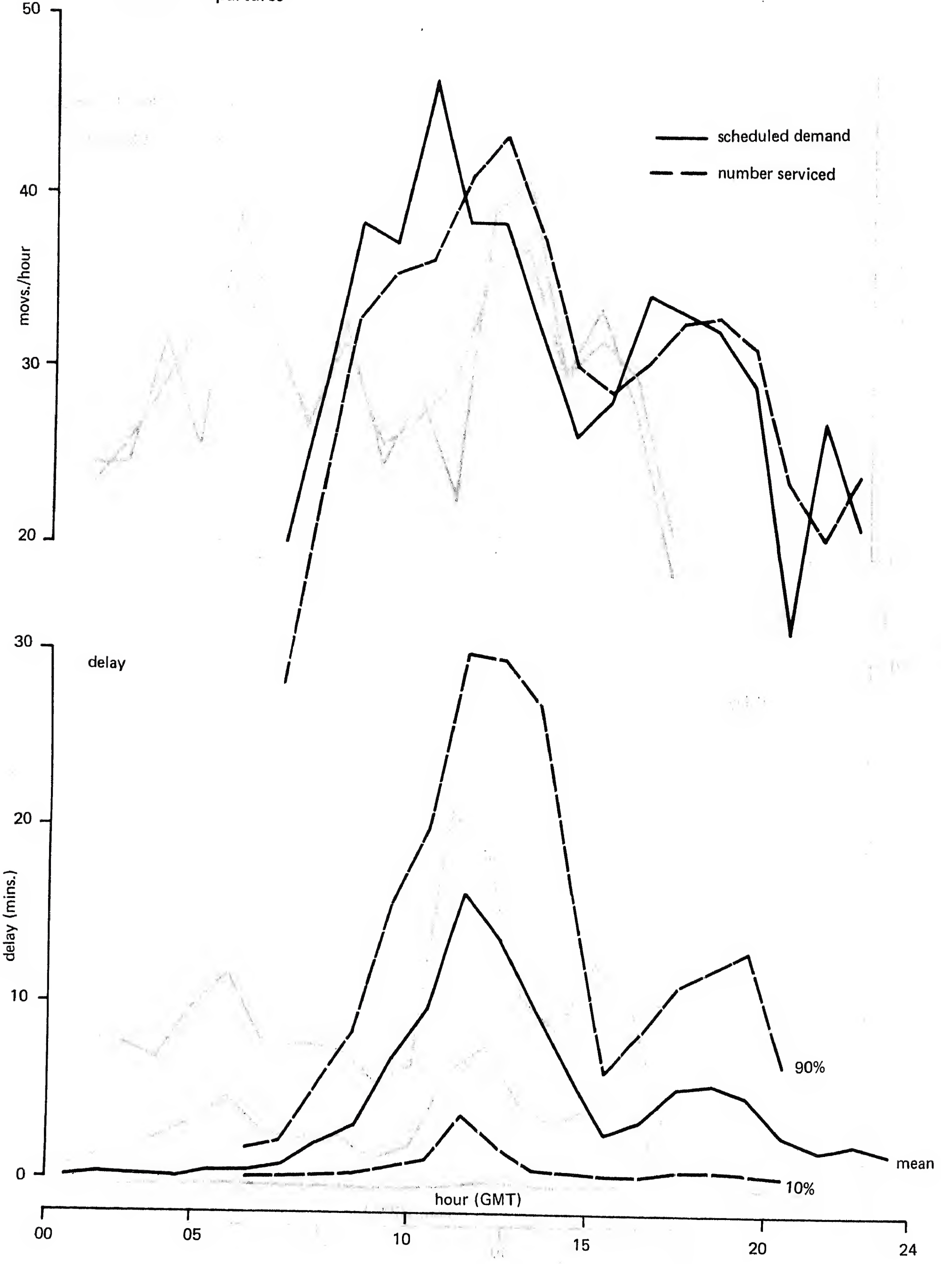


Fig. 12b



Runway Simulation Model (improved ATC performance)
1976 – scheduled forecast (incl. G.A. etc.)
Mixed – departures

Fig. 13a

Runway Simulation Model (improved ATC performance)
1978 – scheduled forecast (incl. G.A. etc.)
segregated arrivals

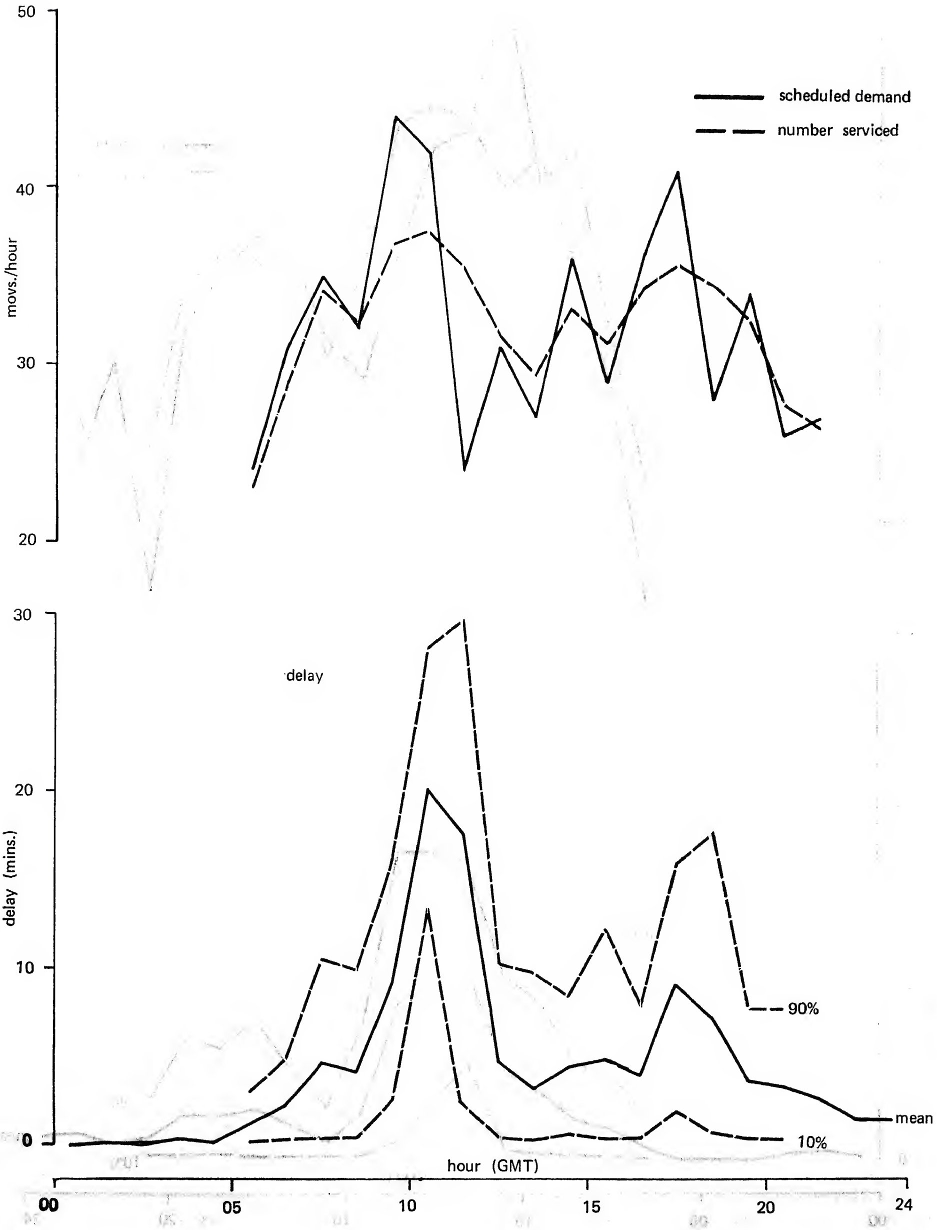


Fig. 13b

Runway Simulation Model (improved ATC performance)
1978 – scheduled forecast (incl. G.A. etc.)
Segregated departures

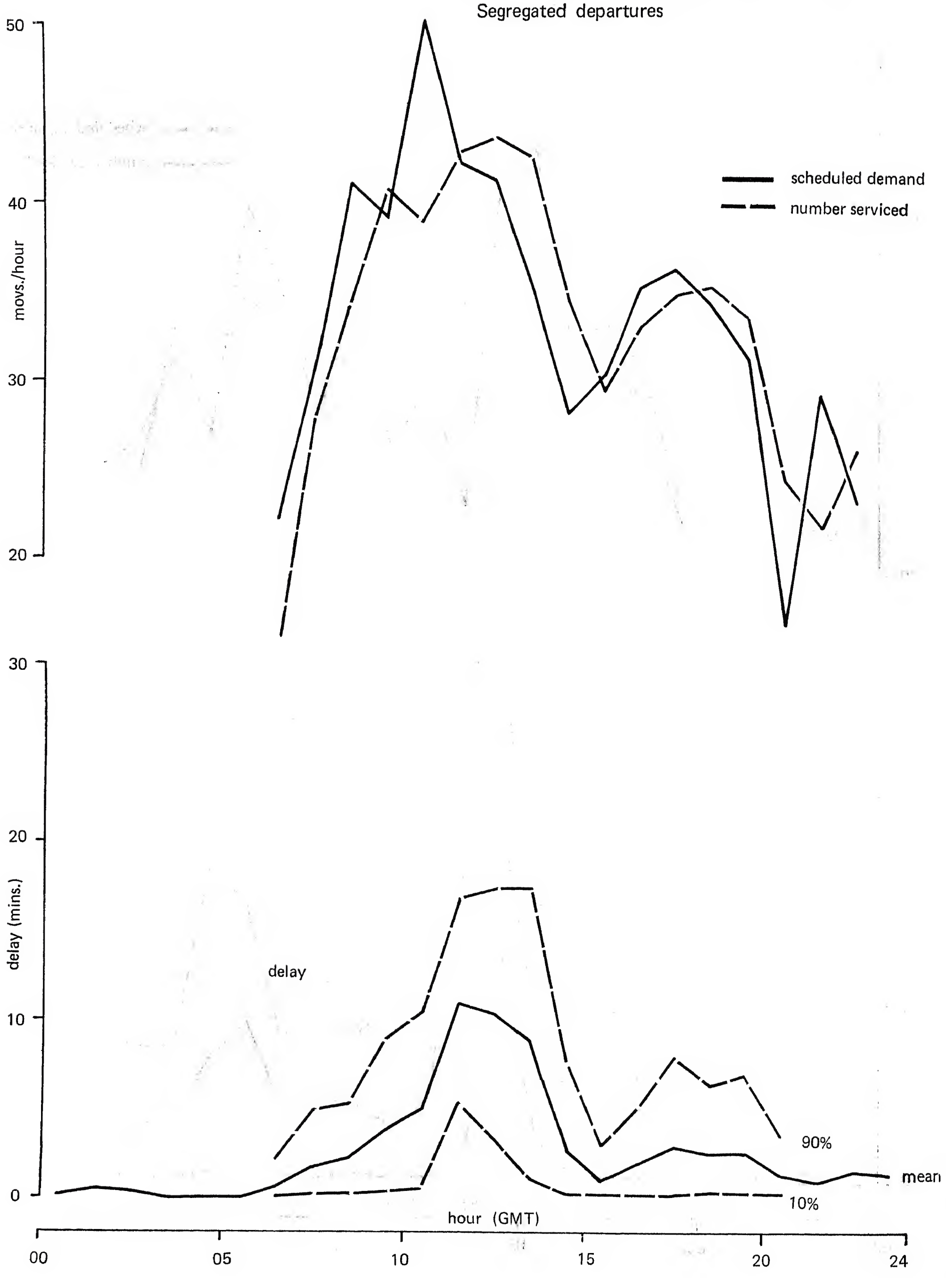


Fig. 14a

Runway Simulation Model (improved ATC performance)
1978 – scheduled forecast (incl. G.A. etc.)
Mixed – arrivals

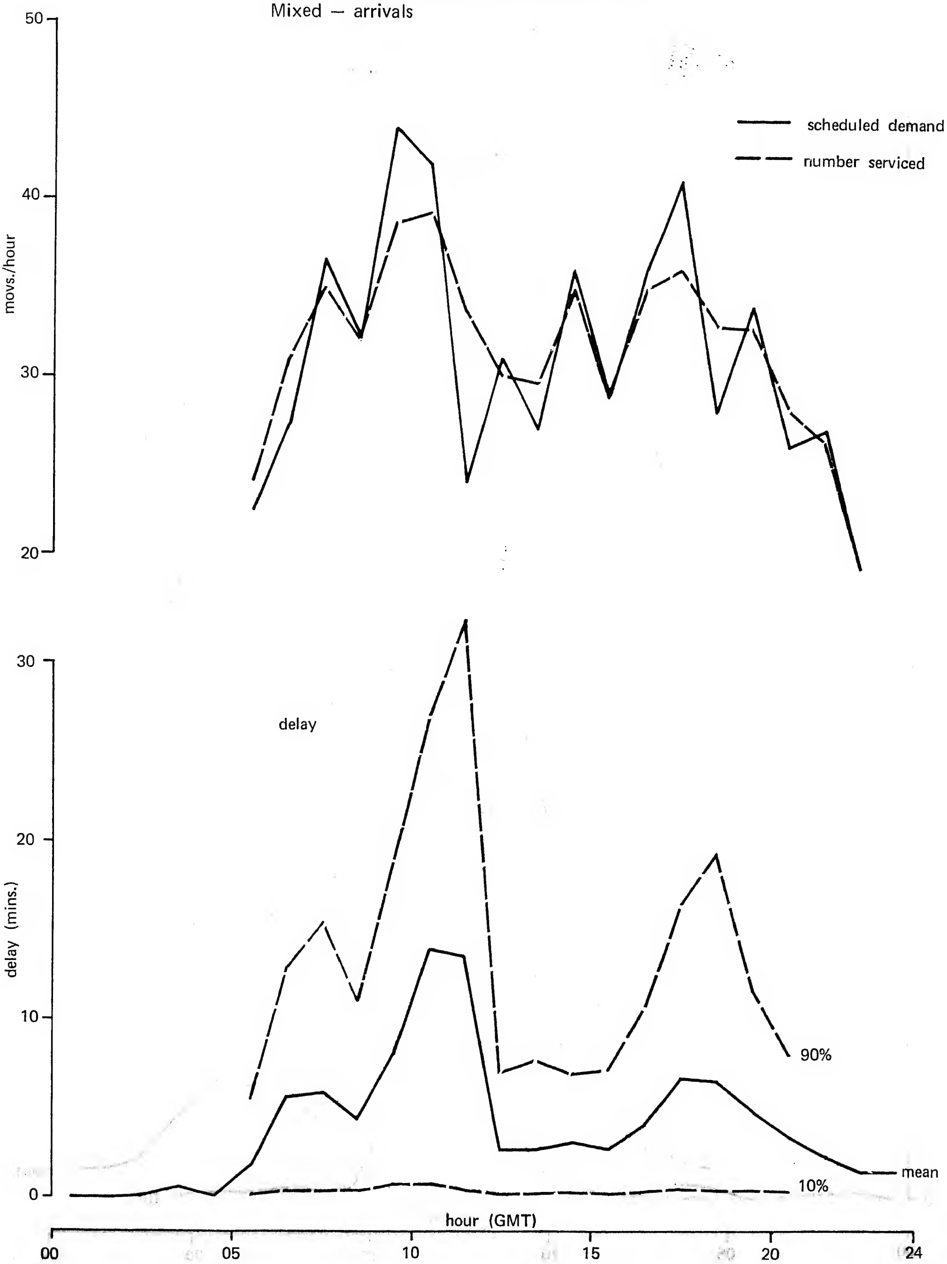


Fig. 14b

Runway Simulation Model (improved ATC performance)
1978 – scheduled forecast (incl. G.A. etc.)
Mixed – departures

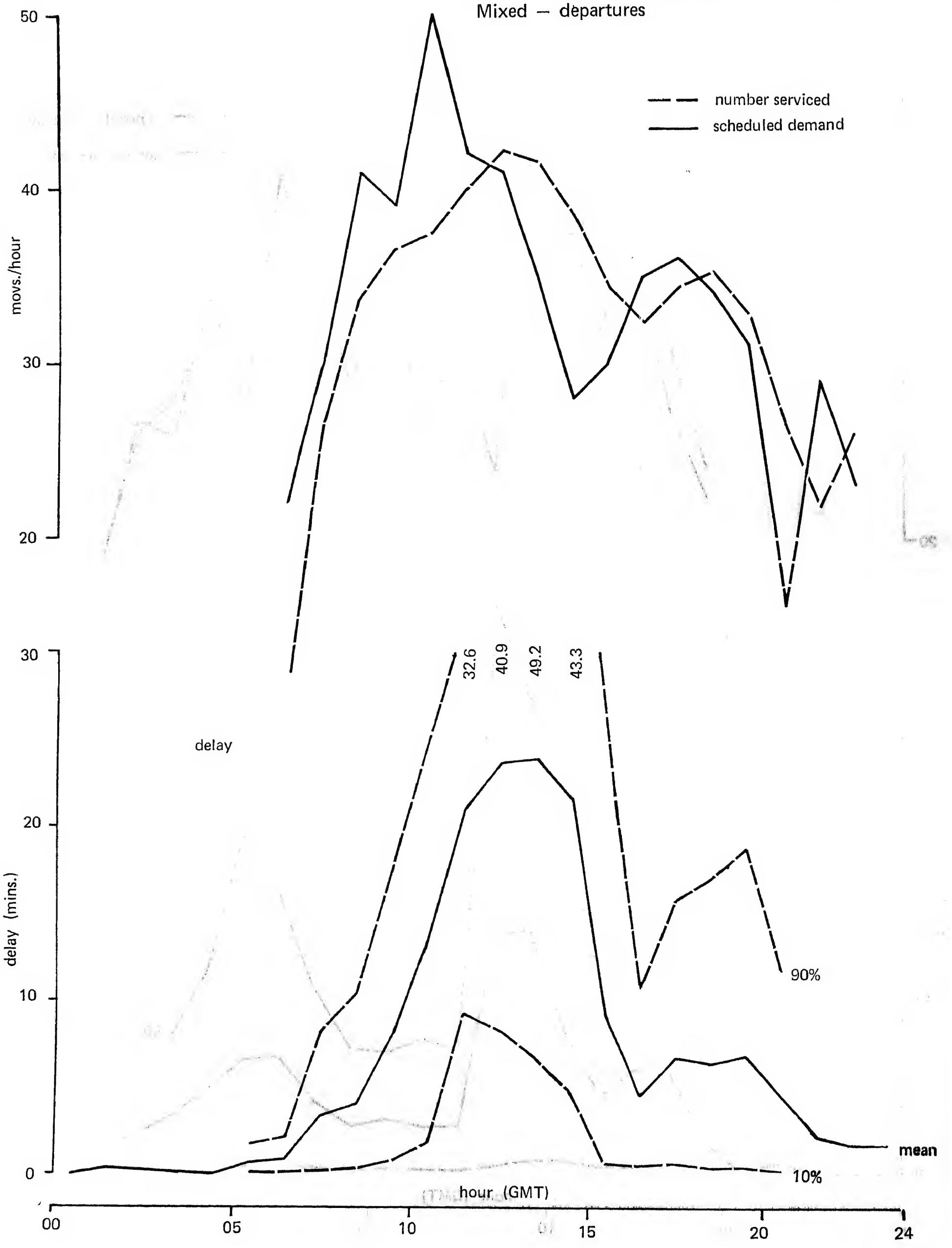


Fig. 15a

Mean delay per aircraft versus aircraft demand as a percentage of the service rate
— Arrivals —

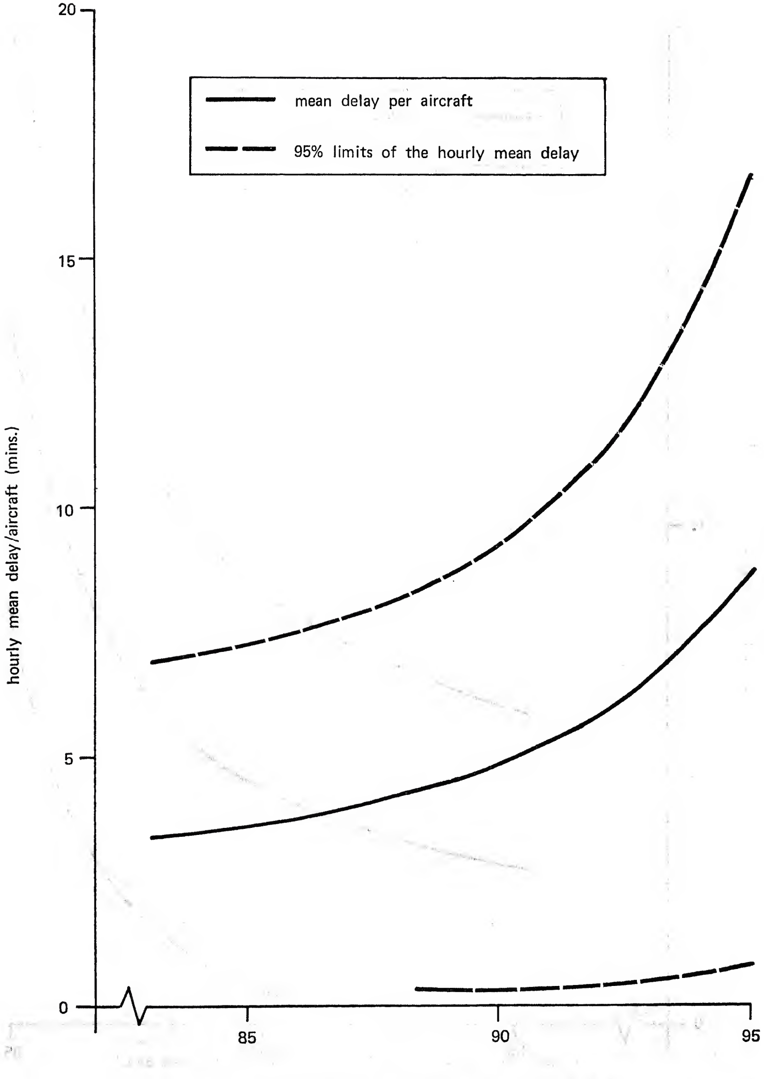
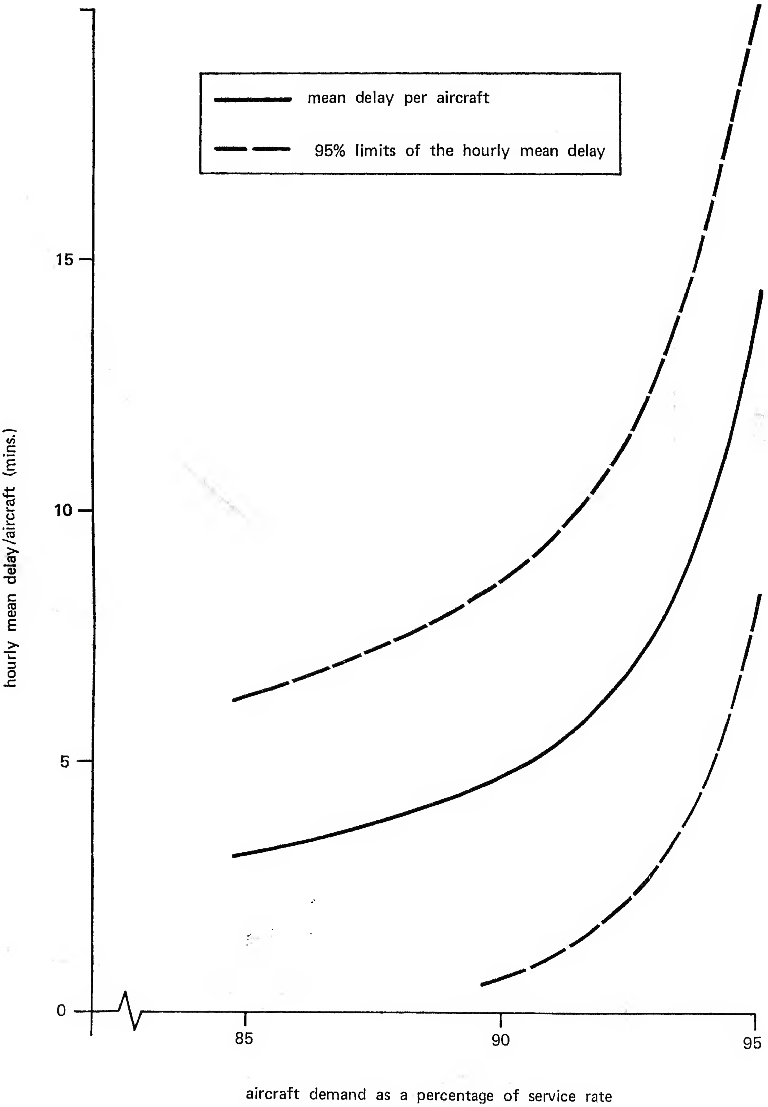


Fig. 15b

Mean delay per aircraft versus aircraft demand as a percentage of the service rate
— Departures —



APPENDIX 5

Revision of Traffic Forecasts

In the year since the forecast was first made for this Working Party and submitted in evidence to the Roskill Commission, events have led to a change of view on the ways in which the air transport market is developing calling for some revision of some aspects of the forecast. The main events which have been considered are the large increases in traffic with North America in 1969 and the continuing slow growth of domestic traffic in that year. The demise of British Eagle resulted in a loss of service at Heathrow on the domestic trunk route to Glasgow and on charter services to Europe, North America and other long-haul routes. Gatwick's fast growth in 1969 is attributed largely to the transfer of some of these services from Heathrow to Gatwick, where they were taken up by other operators.

In the future, the start of BEA Air Tours operations at Gatwick is likely to lead to some reshuffling of traffic between operators at Gatwick, some diversion of charter traffic from other airports in the London vicinity such as Luton, Stansted and Southend and a small transfer of inclusive tour passengers from scheduled services at Heathrow to charter services at Gatwick. A one per cent diversion of Heathrow's scheduled traffic to Europe has been incorporated in the forecast but no specific allowance has been made for other changes. If a quarter of a million passengers were to be attracted to Gatwick in 1970 from other airports not included in the forecast, and this block of traffic were to stay at Gatwick in the future, the Gatwick forecasts of European traffic would need to be increased by about ten per cent. Other changes may flow from BUA's change of ownership but these are too uncertain to enable any worthwhile estimates to be made of future traffic developments.

Traffic demand

North America traffic increased by a quarter in 1969, including a two thirds increase in charter traffic. Further buoyant traffic growth is likely, boosted by route expansion and new promotional fares. The previous forecasts incorporated annual growth rates which declined steadily over the next decade because of the small potential for diversion from sea traffic: this decline has now been postponed five years. Domestic traffic growth has been retarded in the last five years to an average annual growth of less than four per cent. Some recovery is expected, but taking into account fare increases and the planned extension of railway electrification to Glasgow, domestic growth rates have been reduced to a most likely seven and a half per cent per annum with a range of plus or minus one and a half per cent.

The overall effect, shown in table 1, is that total traffic in 1975 is forecast at much the same level as previously, but the 1980 passenger forecasts have been increased by about two and a half per cent.

Passengers per plane

In the previous forecast the same estimates of passengers per plane were used with the most likely, and the upper and lower limit passenger demand forecasts. It is now judged that we should adopt a lower growth rate in passengers per plane for the lower passenger forecast, thereby narrowing the range of the aircraft movement forecast. All-cargo movements are included in the forecast and an assumption about the rate of increase of these movements vis a vis passenger aircraft movements is implicit in the growth assumptions of passengers per plane. The higher rates of increase in all-cargo movements in recent years have contributed to the below average rates of increase in passengers per plane and these high growth rates are expected to continue. To take account of this, the growth rates in passengers per plane for the most likely and lower limit passenger demand forecasts have been slightly reduced. In the long term trend forecasts, the annual rates of increase in planeloads for the most likely case are now 5·8 per cent in 1970 reducing to 5·5 per cent in 1980 with figures 0·3 per cent higher for the upper limit passenger demand and 0·3 per cent lower for the lower limit of demand. The average planeload increases from 60 passengers in 1968 to 120 plus or minus 5 in 1980. In the short term, higher rates of increase of about 8 per cent per annum are forecast for a few years to recover from the recent position when actual values have been less than the long term trends.

The net outcome, shown in table 2, is that in 1975 the forecast range in aircraft movements has narrowed to 335-366-396 compared with 321-363-401 previously and in 1980 the revised forecast is 406-467-522 compared with 369-450-523 previously. The most likely forecast in 1974 is now equivalent to the lower limit forecast in 1976 and the upper limit forecast in 1973, a range of three years compared with about five years before.

By 1978 the range increases between two years earlier for the upper limit and three years later for the lower limit growth forecasts.

Division of traffic between Heathrow and Gatwick

The 1969 rates of passenger traffic increase are compatible with the following transfers of Heathrow's traffic to Gatwick as a result of the closure of British Eagle in November 1968:

(a) 1·5 per cent of domestic traffic.

(b) 72 per cent of Europe charter traffic.

(c) 20 per cent of North Atlantic charter traffic.

(d) 45 per cent of other long-haul charter traffic.

These are assumed to be permanent transfers in the forecast and in addition from 1970 onwards, inclusive tour traffic comprising one per cent of Heathrow's scheduled Europe traffic, amounting to about 80,000 passengers in 1970, is assumed to be diverted to Gatwick charter services.

Resulting forecasts of passenger demand are in table 3 for Heathrow and table 5 for Gatwick with the corresponding air transport movement forecasts in tables 4 and 6.

Compared with the previous forecasts the Heathrow most likely forecast level is deferred by about one year up to 1975, but this difference reduces to nothing by 1980. In 1977 the most likely level is three years ahead of the lower limit and nearly two years behind the upper limit forecast. At Gatwick the 1975 most likely forecast is three years in advance of the previous forecast with a range of one year earlier to two years later. If in addition to the traffic included in the Gatwick forecast, further traffic were to be attracted to Gatwick from other airports in south east England, the Gatwick traffic would increase more quickly. BEA Air Tours expect to attract some traffic from other airports but the long term effects are difficult to predict. Such a diversion of a quarter of a million passengers in 1970 is probably a maximum figure and this would represent a ten per cent increase in the forecast levels of Europe air traffic at Gatwick. A long term diversion of this block of traffic to Gatwick from airports other than Heathrow, would advance the Gatwick total forecast by up to one year.

Busy day traffic forecasts

The forecast ratio of air transport movements on the 15th busiest day to annual traffic at Heathrow is unchanged from the previous forecast. The slight changes in traffic mix affect the distribution of movements between airlanes at different hours of the day and the aircraft type mix, but these changes are assumed to be small enough to have no significant effect on the delay distributions produced by the simulation model.

Board of Trade
Stats 6

March 1970

Table 1
Forecast of terminal passenger demand at airports in the London area (currently Heathrow and Gatwick)
Short term trends above and long term trends below the line.
MILLIONS

Year	Europe			Irish Republic			North America			Other long-haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		8·4			0·8			1·9			1·0			12·1			3·1			15·2	
1969 (Estimate)		9·5			0·9			2·4			1·1			13·9			3·2			17·1	
1969 (Long term trend)	9·4	9·7	10·0	0·9	0·9	0·9	2·3	2·4	2·4	1·2	1·2	1·3	13·8	14·2	14·7	3·4	3·5	3·6	17·2	17·7	18·3
1970	10·3	10·6	10·8	0·9	0·9	1·0	2·7	2·8	2·9	1·3	1·4	1·4	15·3	15·7	16·0	3·4	3·5	3·5	18·7	19·2	19·5
1971	11·3	12·0	12·3	1·0	1·0	1·1	3·1	3·2	3·4	1·5	1·6	1·6	16·8	17·7	18·3	3·7	3·8	3·9	20·5	21·6	22·2
1972	12·3	13·4	13·9	1·0	1·1	1·2	3·5	3·7	4·0	1·6	1·8	1·8	18·5	20·0	20·9	4·0	4·2	4·4	22·5	24·2	25·3
1973	13·5	14·9	15·8	1·1	1·2	1·3	4·0	4·3	4·6	1·8	2·0	2·1	20·3	22·4	23·9	4·3	4·6	4·9	24·6	27·0	28·8
1974	14·7	16·5	17·9	1·2	1·3	1·4	4·5	5·0	5·4	2·0	2·2	2·4	22·4	25·0	27·2	4·6	5·0	5·5	27·0	30·0	32·7
1975	16·1	18·3	20·3	1·2	1·4	1·6	5·1	5·7	6·3	2·2	2·5	2·8	24·7	27·9	31·0	4·8	5·4	6·0	29·5	33·3	37·0
1976	17·6	20·3	22·7	1·3	1·5	1·7	5·8	6·5	7·3	2·5	2·8	3·2	27·2	31·2	34·9	5·1	5·8	6·6	32·3	37·0	41·5
1977	19·2	22·5	25·4	1·4	1·6	1·8	6·6	7·5	8·5	2·7	3·2	3·6	29·9	34·8	39·3	5·4	6·2	7·2	35·3	41·0	46·5
1978	21·0	24·9	28·3	1·5	1·7	2·0	7·4	8·5	9·8	3·0	3·6	4·1	32·8	38·8	44·2	5·7	6·7	7·8	38·6	45·5	52·0
1979	22·9	27·6	31·6	1·5	1·8	2·1	8·3	9·7	11·3	3·4	4·1	4·7	36·1	43·2	49·7	6·1	7·2	8·5	42·2	50·4	58·2
1980	25·0	30·6	35·3	1·6	2·0	2·3	9·3	11·0	13·0	3·8	4·6	5·3	39·6	48·1	55·8	6·5	7·8	9·3	46·1	55·9	65·1

Table 2

Forecast of air transport movement demand at airports in the London area (currently Heathrow and Gatwick)

Short term trends above and long term trends below the line.

THOUSANDS

Year	Europe			Irish Republic			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		149			16			26			20			211			55			266	
1969 (Estimate)		160			15			30			23			228			58			286	
1969 (Long term trend)	154	158	162	15	15	15	26	27	27	18	19	19	213	219	223	54	56	57	267	275	280
1970	165	168	169	15	15	15	31	31	32	22	23	23	233	238	239	58	59	60	291	297	299
1971	168	176	178	15	16	16	31	32	33	22	23	23	236	246	250	59	60	62	295	307	312
1972	172	184	187	16	16	17	32	33	34	22	23	23	241	256	262	60	62	65	301	318	327
1973	180	193	200	16	17	18	34	36	37	22	23	23	250	268	279	60	63	67	310	332	346
1974	187	203	215	16	18	19	37	38	40	22	23	25	261	283	299	61	66	72	322	349	371
1975	194	214	229	17	18	20	39	41	44	23	24	26	272	298	320	62	68	76	335	366	396
1976	202	225	242	17	19	21	41	44	47	24	26	28	284	314	339	64	70	80	348	384	419
1977	211	237	256	17	19	22	43	47	51	25	27	30	296	331	359	65	73	84	361	403	443
1978	220	249	271	17	20	23	46	50	55	26	29	31	309	348	380	66	75	88	376	423	468
1979	229	262	286	18	20	23	49	54	60	27	31	33	323	367	402	68	78	92	391	445	494
1980	239	276	302	18	21	24	52	57	64	28	32	36	337	387	426	69	80	96	406	467	522

Table 3
Forecast of terminal passenger demand at Heathrow
Short term trends above and long term trends below the line.
MILLIONS

Year	Europe			Irish Republic			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		7·1			0·8			1·7			0·8			10·4			2·7			13·2	
1969 (Estimate)		7·6			0·9			2·0			0·9			11·3			2·8			14·1	
1970	8·1	8·3	8·4	0·9	0·9	0·9	2·3	2·3	2·4	1·0	1·1	1·1	12·3	12·6	12·8	3·0	3·1	3·1	15·3	15·7	15·9
1971	8·7	9·3	9·5	1·0	1·0	1·0	2·6	2·7	2·8	1·2	1·3	1·3	13·4	14·2	14·6	3·3	3·4	3·5	16·7	17·6	18·1
1972	9·4	10·2	10·6	1·0	1·1	1·2	2·9	3·1	3·3	1·3	1·4	1·5	14·7	15·9	16·6	3·6	3·7	3·9	18·3	19·6	20·5
1973	10·2	11·3	12·0	1·1	1·2	1·3	3·3	3·6	3·8	1·5	1·6	1·7	16·1	17·7	18·9	3·8	4·1	4·3	19·9	21·8	23·2
1974	11·1	12·4	13·5	1·2	1·3	1·4	3·8	4·2	4·5	1·6	1·8	2·0	17·7	19·7	21·4	4·0	4·4	4·8	21·7	24·1	26·2
1975	12·0	13·6	15·1	1·2	1·4	1·5	4·3	4·8	5·2	1·8	2·1	2·3	19·4	21·9	24·2	4·2	4·7	5·3	23·6	26·7	29·5
1976	13·0	15·0	16·8	1·3	1·5	1·7	4·9	5·5	6·1	2·0	2·3	2·6	21·2	24·4	27·2	4·5	5·1	5·8	25·7	29·5	33·0
1977	14·1	16·5	18·7	1·4	1·6	1·8	5·4	6·3	7·0	2·2	2·6	3·0	23·1	27·1	30·5	4·8	5·5	6·3	27·9	32·5	36·8
1978	15·3	18·2	20·7	1·4	1·7	1·9	6·2	7·2	8·1	2·5	3·0	3·4	25·4	30·0	34·1	5·0	5·9	6·9	30·5	35·9	41·0
1979	16·5	20·0	22·9	1·5	1·8	2·1	7·0	8·2	9·4	2·8	3·4	3·8	27·8	33·3	38·2	5·4	6·3	7·5	33·1	39·6	45·7
1980	17·9	21·9	25·3	1·6	1·9	2·2	7·8	9·2	10·7	3·1	3·8	4·4	30·4	36·9	42·7	5·7	6·8	8·2	36·0	43·7	50·8

Table 4
Forecast of air transport movement demand at Heathrow
Short term trends above and long term trends below the line.
THOUSANDS

	Europe			Irish Republic			North America			Other Long-Haul			Total International			Domestic			Total		
Year	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		127			16			25			17			184			45			229	
1969 (Estimate)		131			15			28			19			192			45			237	
1970	132	135	136	15	15	15	28	29	29	19	20	20	194	198	200	45	46	46	239	244	246
1971	133	140	141	15	16	16	29	30	30	19	20	20	196	204	207	46	47	48	242	251	256
1972	136	145	148	16	16	17	30	31	31	19	20	20	199	211	216	46	48	50	246	259	266
1973	140	151	157	16	17	18	32	33	34	19	20	20	206	220	229	47	49	52	252	269	281
1974	145	158	167	16	18	19	34	35	37	19	20	21	213	231	245	47	51	56	261	282	300
1975	150	165	177	17	18	20	36	38	40	19	21	23	222	242	260	48	53	59	270	295	319
1976	155	172	186	17	19	21	38	41	43	20	22	24	230	254	274	49	54	62	279	308	336
1977	160	180	195	17	19	22	40	43	47	21	23	25	238	266	289	50	56	65	289	323	354
1978	166	188	205	17	20	23	43	46	50	22	25	27	248	279	305	52	58	68	300	338	373
1979	172	197	215	18	20	23	45	50	54	23	26	29	258	293	321	53	60	71	310	353	393
1980	178	206	225	18	21	24	48	53	59	24	28	31	268	308	339	54	62	75	322	370	413

Table 5

Forecast of terminal passenger demand at Gatwick

Short term trends above and long term trends below the line.

MILLIONS

Year	Europe			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		1·4			0·2			0·2			1·7			0·3			2·1	
1969 (Estimate)		2·0			0·4			0·2			2·6			0·4			3·0	
1970	2·3	2·4	2·4	0·5	0·5	0·5	0·2	0·2	0·2	3·0	3·1	3·1	0·4	0·4	0·4	3·4	3·5	3·6
1971	2·6	2·8	2·8	0·5	0·5	0·6	0·3	0·3	0·3	3·4	3·5	3·7	0·5	0·5	0·5	3·8	4·0	4·2
1972	2·9	3·2	3·3	0·6	0·6	0·7	0·3	0·3	0·3	3·8	4·1	4·3	0·5	0·5	0·5	4·3	4·6	4·8
1973	3·3	3·6	3·8	0·6	0·7	0·8	0·3	0·4	0·4	4·2	4·6	5·0	0·5	0·6	0·6	4·8	5·2	5·6
1974	3·7	4·1	4·5	0·7	0·8	0·9	0·4	0·4	0·4	4·7	5·3	5·8	0·6	0·6	0·7	5·3	5·9	6·5
1975	4·1	4·7	5·1	0·8	0·9	1·1	0·4	0·5	0·5	5·3	6·0	6·7	0·6	0·7	0·7	5·9	6·7	7·5
1976	4·6	5·3	5·9	0·9	1·0	1·3	0·4	0·5	0·6	6·0	6·8	7·7	0·6	0·7	0·8	6·6	7·5	8·5
1977	5·1	6·0	6·7	1·0	1·2	1·5	0·5	0·6	0·6	6·7	7·7	8·8	0·7	0·8	0·9	7·3	8·5	9·7
1978	5·7	6·8	7·7	1·2	1·3	1·7	0·5	0·7	0·7	7·4	8·8	10·1	0·7	0·8	0·9	8·1	9·6	11·1
1979	6·4	7·7	8·7	1·3	1·5	2·0	0·6	0·7	0·8	8·3	9·9	11·5	0·7	0·9	1·0	9·0	10·8	12·6
1980	7·1	8·7	9·9	1·5	1·7	2·2	0·7	0·8	0·9	9·3	11·2	13·2	0·8	0·9	1·1	10·0	12·2	14·3

Table 6

Forecast of air transport movement demand at Gatwick

Short term trends above and long term trends below the line.

THOUSANDS

Year	Europe			North America			Other Long-Haul			Total International			Domestic			Total		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1968 (Actual)		23			1			3			27			11			38	
1969 (Estimate)		30			2			4			36			13			49	
1970	33	34	34	2	2	3	3	3	3	39	39	40	13	13	14	52	53	53
1971	35	36	37	2	2	3	3	3	3	40	42	43	13	14	14	54	56	57
1972	37	39	39	3	3	3	3	3	3	42	45	46	13	14	15	56	59	61
1973	39	42	43	3	3	3	3	3	3	45	48	50	13	14	15	58	62	65
1974	42	45	48	3	3	3	3	3	4	48	52	55	14	15	16	61	66	71
1975	44	49	52	3	3	4	3	4	4	51	55	60	14	15	17	65	71	77
1976	47	52	56	3	3	4	3	4	4	54	60	65	14	16	18	68	76	82
1977	51	57	61	3	4	4	4	4	4	58	64	70	15	16	19	72	81	88
1978	54	61	66	4	4	5	4	4	4	61	69	75	15	17	20	76	86	95
1979	57	65	71	4	4	5	4	4	5	65	74	81	15	18	21	80	91	102
1980	61	70	77	4	4	6	4	5	5	69	79	87	16	18	22	85	98	109

APPENDIX 6

Ability of Gatwick to accept movements transferred from Heathrow

1. In attempting to assess the ability of Gatwick to accept movements transferred from Heathrow it is necessary to forecast two items—the future capacity of Gatwick in terms of movements per hour; and the future demand by what might be termed 'Gatwick's own traffic', again in terms of movements per hour; subtracting the latter from the former will produce an estimate of the 'spare capacity' available for transfers.

Future Gatwick capacity

2. Paragraph 4.2.3.1 of the WPTC Report deals with the future capacity of Gatwick and shows that there are three possible positions: one runway (as at present) giving a sustainable capacity of 35-40 movements an hour; two runways which could not be worked independently (45-50 an hour), and two runways which would have some scope for independent operation (60 plus an hour). For convenience it is sufficient to consider the first and the last and deal in terms of 40 movements and 60 movements an hour respectively. These figures refer to the total numbers of movements which would be possible and they must therefore be reduced by the non-air transport movements (i.e. positioning flights, general aviation, club and training flights, etc.) which will take place each hour. Experience has shown at Heathrow that, despite the great pressure for scheduled service slots, about 4 non-air transport movements must be allowed for in each peak hour. Although Gatwick's total of air transport movements is much lower than Heathrow's the former's larger proportion of charter traffic probably leads to proportionately more positioning flights. Further, the fact that there is such pressure on general aviation flights at Heathrow has led to many of these movements taking place at Gatwick. It therefore seems reasonable to assume a figure of 4 non-air transport movements for each peak hour, at Gatwick also, thus effectively reducing the capacities to be considered to 36 and 56 an hour.

Future Gatwick demand

3. Table 6 to Appendix 5 to the WPTC Report contains the revised forecasts of air transport movements at Gatwick for the years up to 1980: the problem is to convert those annual details to hourly rates for the peak summer months—the period with which we are most closely concerned. Two methods of achieving this conversion have been tried and the results are compared below.

4. The first method is to forecast the ratio of the standard busy rate (SBR) to the annual total of air transport movements (ATMs) and then to apply that ratio to the annual forecast (the SBR concept is widely used in expressing airport demand and is taken as the rate of demand in the 30th busiest hour of the year).

5. The ratios experienced at Gatwick over the past three years were:

1967	·00049
1968	·00043
1969	·00041

the comparable figure for Heathrow for 1969 was ·00026. These figures reflect the fact that Heathrow's demand, which on a number of occasions reaches the maximum acceptable level of movements per hour, is more evenly spread throughout the week and throughout the year than Gatwick's; but that the latter is moving towards a more even spread. It would seem sensible to assume that the ratio will continue to reduce at Gatwick—even if not down as far as the Heathrow figure. But there are arguments in favour of believing that, because of the nature of the traffic (e.g. the large proportion of holiday charter and IT flights) this reduction will slow considerably—especially at a time when there is still room in even the peak hours for more movements. A safely conservative policy would be to assume the ratio to be ·00040 throughout the decade. Applying this ratio to the forecasts produces estimated demands by 'Gatwick's own traffic' in terms of movements per hour. Subtracting these forecasts from available capacity gives the following estimates of 'spare' capacity available for Heathrow transfers:

Table 1

Gatwick 'spare' capacity—ATMs per hour
(at SBR i.e. in the 30th busiest hour)

	with one runway			with two runways		
	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1974	12	10	8	32	30	28
1975	10	8	5	30	28	25
1976	9	6	3	29	26	23
1977	7	4	1	27	24	21
1978	6	2	—	26	22	18

6. The second method differs from the first in that it is based upon the ratio of a daily total of movements to the annual total. In forecasting the daily movement demand at Heathrow for the simulation exercise, attention was focused on one representative day in each of the typical periods—'peak', 'off-peak' and 'shoulder'. The representative day for the 'peak' period was taken as the 15th busiest day (which in fact occurred in August—see Section 8 of Appendix 1 to the WPTC Report). The ratio of the 15th busiest day to annual air transport movements at Gatwick was:

1967	·0065
1968	·0058
1969	·0057

the comparable figure for Heathrow in 1969 was ·0035. As with the SBR/ATM ratio it seems, at first sight, logical that the Gatwick ratio will continue to diminish towards the Heathrow level—but here again the nature of the traffic gives reason to doubt that the rate of reduction will be maintained and a figure (again safely conservative) of ·0055 is taken for the whole decade. Applying this figure to the annual totals of air transport movements produces a list of forecasts of daily totals which must be further divided into hourly forecasts by applying ratios of hourly to daily totals.

7. At present some 20 per cent of Gatwick traffic moves at night but this proportion will clearly reduce with the introduction of night flight limitation. The present traffic at Gatwick is far enough below capacity to permit easy re-scheduling of flights as circumstances require and this, together with the nature of the traffic there, contributes to producing an irregular pattern of demand.

8. Despite this it has been assumed that increasing pressure arising from the growing numbers of movements will tend to produce a situation in which there is a more or less even demand throughout the ten hours from 0800 to 1800 GMT and that these hours will contain about 60 per cent of the total daily movements (a little less in the early years but rather more later on, as the total number of movements increases, if the number of permitted night movements is not increased). Applying these concepts to the annual forecasts produces figures for hourly demand by 'Gatwick's own traffic'; subtraction from the forecast total capacity again produces a table of average hourly 'spare capacity':

Table 2

Average 'spare capacity' per hour at Gatwick peak hours (0800–1800 GMT) on the 15th busiest day of the year

	with one runway			with two runways		
Year	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1974	16	14	13	36	34	33
1975	15	13	11	35	33	31
1976	14	11	9	34	31	29
1977	12	9	6	32	29	26
1978	10	7	3	30	27	23

Conclusions

9. Both the methods used are necessarily approximations. Both can be said to be conservative in that they use ratios ('SBR/annual ATM' and '15th busiest day/annual ATM') which are constant throughout the decade and at levels only slightly lower than last year's—thus, it could be argued, ignoring much of the natural peak-spreading between days of the week and months of the year. (But there are sound reasons for assuming that the rate of reduction of the ratios will slow down—see para. 5 above; moreover, if the ratios were to be reduced further there would be little effect upon the timing of any particular circumstances arising—see para. 10 below.) The first method used continues to be conservative in identifying spare capacity in that it makes no allowance for the benefits of 'traffic management'. The second method is more optimistic at this stage in that it postulates a very even level of traffic over 10 hours of the day. (If the level is not even, less capacity for transfer is liable to result because, although the Heathrow and Gatwick peaks may not coincide, in more

cases than not Gatwick's traffic would be above average at Heathrow's peak times.)

10. If the ratios used were assumed to be reduced to, say, SBR/ATM = ·00035 and 15th busiest day/ATM = ·0050 this would increase the amount of peak hour spare capacity available by only 12½ per cent and 9 per cent respectively; since traffic at Gatwick is estimated to grow at about 7 per cent each year this would make a difference of only 1 or 2 years in the achievement of any given state of ability to accept transfers.

11. On the basis of the considerations set out above it seems reasonable to regard the figures in table 1 as a relatively conservative estimate and those in table 2 as a relatively optimistic estimate. Bearing in mind the points in para. 10 above, it seems reasonable to regard the figures in tables 1 and 2 above as defining a range which contains the most likely figures for each year. Narrowing the range slightly by one movement on each side would give the following composite table:

Table 3

Average spare capacity per hour at Gatwick: Air Transport Movements

	with one runway			with two runways		
Year	Lower	Most Likely	Upper	Lower	Most Likely	Upper
1974	13–15	11–13	9–12	33–35	31–33	29–32
1975	11–14	9–12	6–10	31–34	29–32	26–30
1976	10–13	7–10	4–8	30–33	27–30	24–28
1977	8–11	5–8	2–5	28–31	25–28	22–25
1978	7–9	3–6	0–2	27–29	23–26	19–22

12. The situation of Gatwick with two runways quoted in these tables is that obtaining when there is scope for some independence of operations (see para. 2 above). If the two runways could not be operated independently the spare capacity available would be about 10 movements per hour more than the single runway case.

13. BEA considered that the assumed levels of SBR/annual ATM ratios were unduly pessimistic. Taking note of the currently observed faster rate of growth of holiday charter traffic in winter than in summer, the current spreading of holiday traffic over the day as well as through the week and believing in the attractions of traffic management compared with the alternatives, BEA considered that a ratio as low as 0·00030 could be achieved at Gatwick in the latter half of the 1970s. Such a level would increase the 'Average Spare Capacity Per Hour, at Gatwick' quoted in table 3 above by about 5 movements per hour.

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